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P-80

Technology Requirements For Future Earth-To-Geosynchronous Orbit Transportation Systems

FINAL BRIEFING
April, 1979

(NASA-CR-180090) TECHNOLOGY REQUIREMENTS FOR FUTURE EARTH-TO-GEOSYNCHRONOUS ORBIT TRANSPORTATION SYSTEMS Final Report (Boeing Aerospace Co.) 80 p

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CONTRACT NAS1-15301

LANGLEY RESEARCH CENTER

BOEING AEROSPACE COMPANY

Final Oral Report

- STUDY OVERVIEW
- MIDTERM/NORMAL GROWTH SUMMARY
- ACCELERATED TECHNOLOGY ASSESSMENT
- VEHICLE SET DEFINITION & COMPARISONS
- COSTS
- FINDINGS

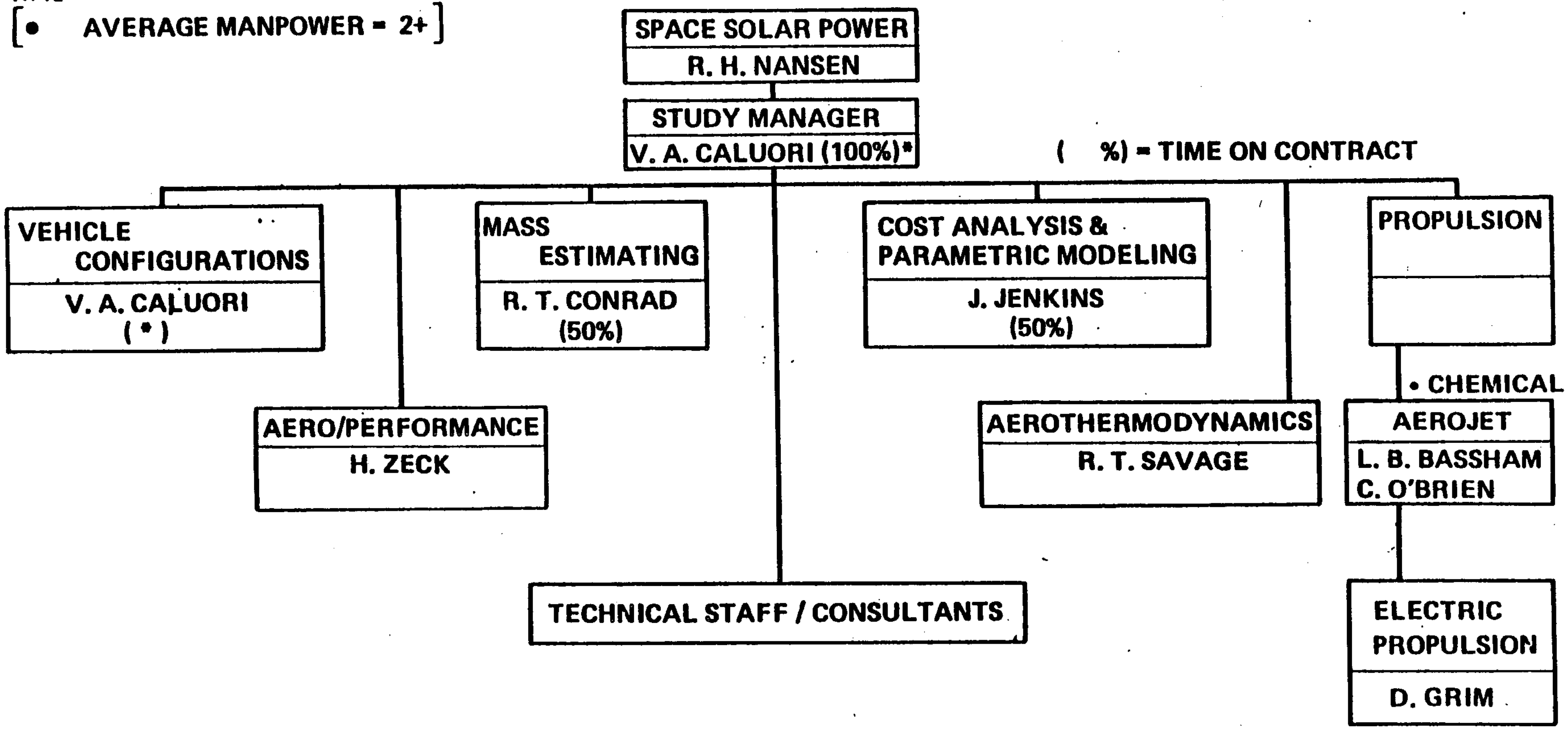
Study Overview

Organization & Manning

TR-12

[• AVERAGE MANPOWER = 2+]

(%) = TIME ON CONTRACT



Study Overview
Objectives, Tasks & Issues

- STUDY OBJECTIVE:

  "IDENTIFY TECHNOLOGY AREAS CRITICAL TO THE DEVELOPMENT OF FUTURE TRANSPORTATION SYSTEMS OR WHICH OFFER SIGNIFICANT COST & PERFORMANCE ADVANTAGES"

- FOUR TASKS:

  1st Half
  - DEFINE NORMAL TECHNOLOGY GROWTH
  - DEFINE EARTH-TO-GEO TRANSPORTATION SYSTEM

  2nd Half
  - APPLY ACCELERATED GROWTH TECHNOLOGY
  - EVALUATE ACCELERATED GROWTH

- SIDE ISSUES:
  - PRIORITY CARGO PAYLOAD COST OPTIMIZATION
  - SHUTTLE CONSTRAINED POTV COMPARISON
  - ELECTRIC VS CHEMICAL LCOTV
  - HLLV WINGED VS BALLISTIC

Study Overview – Key Groundrules

- TOTAL TRANSPORTATION SYSTEM - PRIORITY CARGO & HEAVY LIFT - EARTH TO GEO
- IOC 1990
- ALL ELEMENTS REUSABLE
- SPACE BASING - DEPOT @ 500 KM
- KSC LAUNCH SITE: LEO BASE @ 28.5^0; GEO - EQUATORIAL
- MISSION MODEL SPECIFIED
- HEAVY LIFT PAYLOAD = 227 METRIC TONS
- PRIORITY CARGO PAYLOAD SIZE(S) TO BE COST OPTIMIZED
- PAYLOAD DENSITY = 100 KG/M^3
- RETURN PAYLOADS:

  SSTO - 100%; HLLV - 10%; POTV - 75%; LCOTV - NONE

- ALL WINGED VEHICLES VTO - HL @ 165 KNOTS
- RE-ENTRY TRIM CORRIDERS:

  SSTO 30^0 - 60^0; HHLV 35^0 - 60^0

- SSTO - 2000 KM X-RANGE
- SSTO OMS SIZED FOR 93 X 186 KM INSERTION
- T/W @ LIFTOFF = 1.3, MAX ACCELERATION = 3g
- CH_4 = HYDROCARBON FUEL

Technology Forecasting

- PREVIOUS SSTO STUDIES & JPL FORECAST FORM DATA BASE

NEED:

- UPDATING
- "NORMALIZATION"
- EXPANSION - TO INCLUDE NEW VEHICLES/REQUIREMENTS

OTV'S	CHEMICAL ELECTRICAL
HLLV	ORBITER FLYBACK BOOSTER
SPACE BASING	

METHODOLOGY:

- UNDERSTAND EXISTING DATA BASE
- IN HOUSE CONSULTATION
- OUTSIDE CONTACTS IN SELECTED AREAS

Normal Growth Technology Summary

	SSTO	HHLV	POTV	LCOTV
● STRUCTURES/MATERIALS				
-Improved RSI	X	X		
-"Advanced Composites"	X	X	X	X
-Titanium Honeycomb	X	X		
● PROPULSION				
-SSME Two-Position Nozzle	X	X		
-Hydrocarbon Booster Engine	X	X		
-"ASE" Type Engine	X	X	X	
-LOX/LH_2 RCS	X	X	X	
-50 CM ION Thruster				X
● POWER. PWR. CONV., PWR. DIST.				
-APU Driven Generators/Pumps	X	X		
-8000 PSI Hydraulics	X	X		
-High Voltage/Solid State Elec. Power	X	X	X	X
-GaAs Solar Arrays/Annealable				X
● SUBSYSTEMS				
-Improved Avionics	X	X	X	X
-Improved Landing Gear	X	X		
-2nd Generation Shuttle				
Crew Accommodations	X			
Environmental Control	X	X		
-CCV/FBW Flight Control System	X	X		

Normal Growth Technology

Propulsion

- SSME - 2 POSITION NOZZLE
  E = 50/150 I_{sp} = 450/465 Δ WGT = 173. KG (383 lb)
  Δ COST = \$50M DDT&E
- HYDROCARBON BOOSTER ENGINE
- "ASE" TYPE ENGINE

  I_{sp} = 476 (E = 400)   THRUST = 88,964N. (20Klb)
  WEIGHT = 206.4 KG (455 lb)   COST = \$250M DDT&D
- LOX/LH_2 RCS
  I_{sp} = 427   COST = \$46M DDT&E
- 50 CM ION THRUSTER
- ZERO NPSH BOOST PUMPS FOR ASE, 18 KG (40 LB)/ENGINE

Normal Growth Technology

Hydrocarbon Engine

- EXPANDER BLEED CYCLE - CH_4 FUEL
  - HYDROGEN COOLING & TURBO PUMP DRIVE
  - P_C = 4250 PSIA
  - A_E = 50 • EXIT DIAMETER = 87 Inches
  - I_{SP} = 328 SEA LEVEL → 361 VACUUM
  - THRUST (lbs) = 867,700 S.L. → 955,000 VACUUM
  - DRY WEIGHT = 6,680 lbs • T/W = 143
  - LENGTH = 170 INCHES POWER HEAD DIAM. = 98 INCHES
  - TBO = 250 STARTS (50% REFURBISHMENT)
  - DDT&E = $570M

Normal Growth Technology

Structures/TPS

- IMPROVED RSI
- METALLIC TPS - NOT USED
- ADVANCED COMPOSITES
  - 70% WEIGHT FACTOR VS ALUMINUM
  - "100%" UTILIZATION
- TITANIUM HONEYCOMBS
  - TITANIUM H/C USED FOR ALL LH_2 TANKS IN LAUNCH VEHICLES

Normal Growth Technology

TPS

- IMPROVED RSI
  - 3000^0F REUSE LIMIT @ 20 LB/FT^3 (Leading edges, etc) — (Current Li 2200, redline @ 2700^0F & weighs 22 lb/ft^3)
  - 2300^0F REUSE LIMIT @ 7.5 LB/FT^3 — (Current Li 900, 2300^0F @ 9 lb/ft^3)
  - 2000^0F REUSE LIMIT @ 7.5 LB/FT^3 (Flexible Blanket) — (Current coating limit @ 1200^0F)
- TILE RSI - $200-400/TILE — (Current - $400-700/tile + $50 installation)
- FLEXIBLE RSI — (Current - $50/ft^2)

Normal Growth Technology

Power Conversion & Distribution

- APU DRIVEN GENERATORS/PUMPS
  - ELIMINATE LAUNCH VEHICLE FUEL CELLS
- 8,000 PSI HYDRAULICS
  - 30% WEIGHT REDUCTION
- HIGH VOLTAGE/SOLID STATE ELECTRICAL POWER SYSTEM
  - 40% WEIGHT REDUCTION
- GaAS SOLAR ARRAYS

Normal Growth Technology

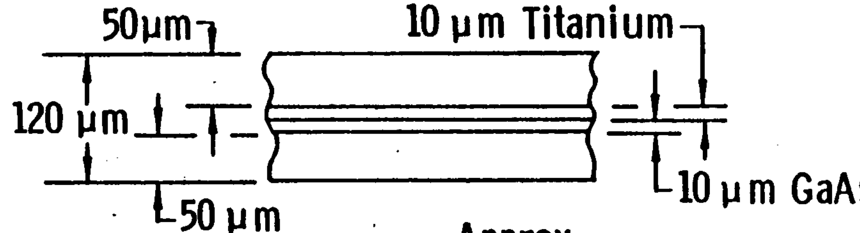
Subsystems

- AVIONICS
  - LOWER WEIGHT, LESS POWER, SAME COST
  - IUS REFERENCE FOR OTV'S, SHUTTLE REFERENCE FOR LAUNCH VEHICLES
- LANDING GEAR
  - NEW SHOCK/STRUT DESIGN USING COMPOSITES, IMPROVED TIRES - 2.8% LANDING WGT.
- CREW ACCOMMODATIONS/ECS
  - 2ND GENERATION SHUTTLE - LOWER WEIGHT
- FLIGHT CONTROL SYSTEM
  - CCV CAPABILITY - SHUTTLE BASED WEIGHTS

Normal Growth Technology

Solar Array

- ANNEALABLE, THIN FILM, GaAs BLANKET



COMPONENT	MATERIAL	$g/m^2/mil$	Thickness (mil)	Approx Area Factor	Mass (g/m^2)
COVER	BORO SILICATE MICROSHEET	55	2.0	1.0	110.0
SOLAR CELL	GaAs	135.13	0.4	0.96	51.9
SUBSTRATE	TITANIUM	114.3	0.4	0.96	43.9
INTERCONNECTS	COPPER	227.1	0.4	0.20	18.2
BACKING/SHIELDING	MICROSHEET	55	2.0	1.0	110.0
		SUBTOTAL			334.0
		TOLERANCES & INSTALLATION (15%)			50.1
		TOTAL			384.1

	EFFICIENCY	POWER
BASIC CELL EFFICIENCY [AM-0, 25°C]	20.0%	270.6 w/m^2
BLANKET PERFORMANCE FACTORS	18.2%	246.0 w/m^2
THERMAL DEGRADATION	17.3%	234.1 w/m^2
RADIATION DEGRADATION	13.8%	186.7 w/m^2

MASS-TO-POWER RATIO $\frac{384.1\ g/m^2}{186.7\ w/m^2}$ = 2.06 g/w or kg/kw

Normal Growth Technology

Ion Thruster

- 50 CM/SHAG OPTICS - LARGEST SINGLE CATHODE DESIGN EXTRAPOLATION OF 30 CM THRUSTER TECHNOLOGY

- ARGON PROPELLANT

THRUST	=	.7 Newtons (.16 lb)
Isp	=	10,000
INPUT POWER	=	46 kw @ 2513 Beam Voltage
EFFICIENCY	=	82%
LIFE	=	6000 Hrs. @ Beam Current = 16 Amps
WEIGHT	=	20 KG (44.1 lb)
REFURBISHMENT REQUIREMENTS	=	50% of Initial Cost (10 rebuilds max)
COST	=	$25M DDT&E

SSTO – Design Requirements & Issues

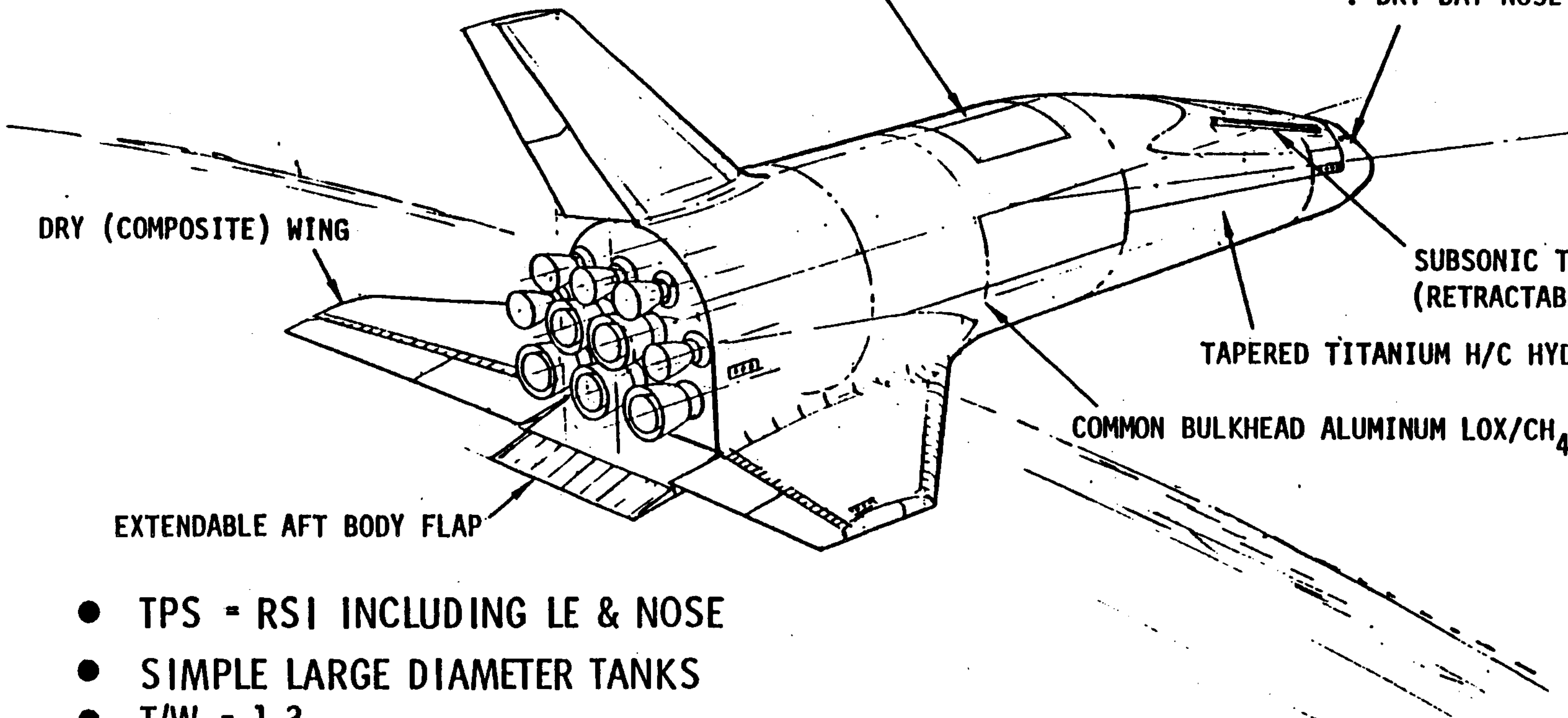
REQUIREMENTS:

- 100 KG/M^3 PAYLOAD DENSITY - 100% RETURN
  - SIZE TO BE COST OPTIMIZED
- OMS SIZED FOR 500 KM FROM 93 X 186 KM INSERTION
- VERTICAL TAKEOFF @ T/W = 1.3 - HORIZONTAL LANDING @ 165 KNOTS
- SINGLE STAGE - DUAL FUEL (METHANE ENGINE PROPELLANT FACTION $\approx$ .6)
- 2000KM X-RANGE (REENTRY TRIM 30^0 - 60^0)
- MINIMUM ORBIT STAY TIME

ISSUES:

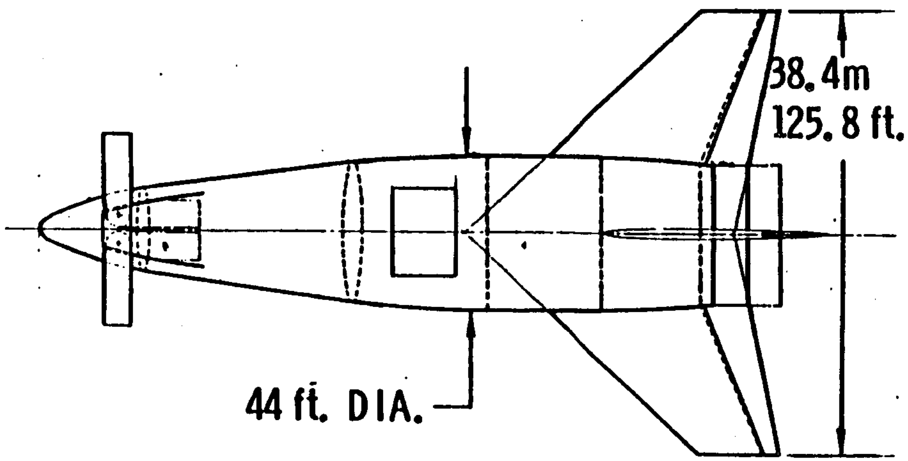
- PAYLOAD SIZE
- PAYLOAD BAY CONFIGURATION & ACCESS
- AERO CONFIGURATION/CG
- STRUCTURAL SIMPLICITY & HIGH VOLUMETRIC EFFICIENCY
- ENGINE SIZE SELECTION

SSTO – Design Concept

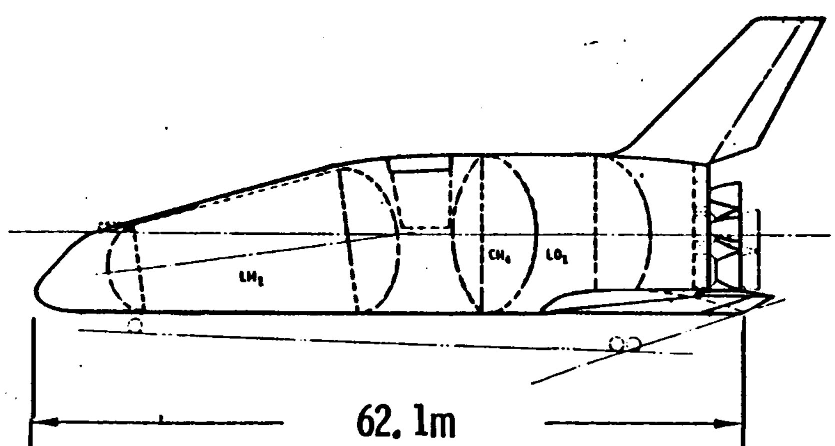


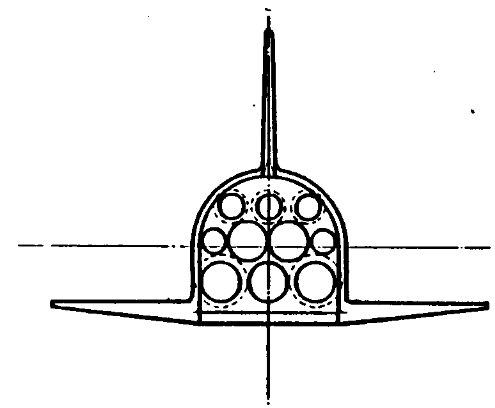
- TPS = RSI INCLUDING LE & NOSE
- SIMPLE LARGE DIAMETER TANKS
- T/W = 1.3
- DUAL FUEL USING CH_4 ENG'S & SSME'S
- 500 FLIGHT LIFE CRITERIA
- LOX/LH_2 RCS & OMS
- WING/CANARD SIZED FOR LANDING

SSTO Configuration



GLOW	2,207,936 KG	(4,868,500 LB)
P/L WT. (100% RETURN)	13,605 KG	(30,000 LB)
PROP. WT. - CH_4 ENGINES	1,188,571 KG	(2,620,800 LB)
PROP. WT. - SSME's - INCL. FPR	767,438 KG	(1,692,200 LB)
INERT WEIGHT	238,322 KG	(525,500 LB)





HLLV

Design Requirements & Issues

REQUIREMENTS:

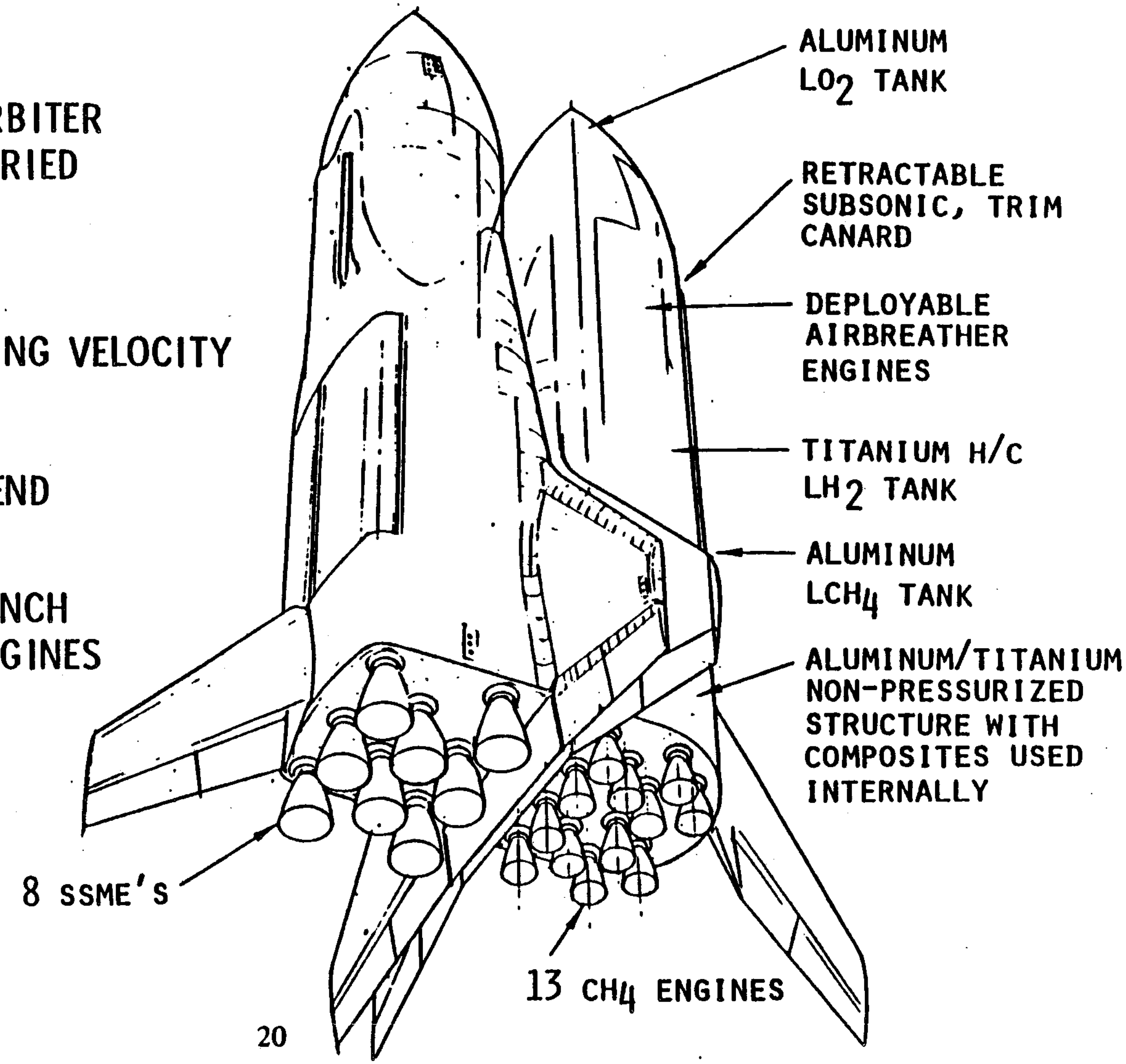
- 227 M.T. TO 500 KM & 28.5^0 INCLINATION - 10% RETURN
- 100 KG/M^3 PAYLOAD DENSITY
- TWO STAGE-PARALLEL BURN WITH X-FEED (LH_2 & LOX)
- VERTICAL TAKEOFF @ T/W = 1.3 - HORIZONTAL LANDING @ 165 KNOTS
- HEAT SINK BOOSTER - AIRBREATHING FLYBACK SYSTEM
- UNMANNED VEHICLES
- 500 MISSION LIFE
- MINIMUM ORBIT STAY TIME

ISSUES:

- PAYLOAD BAY CONFIGURATION & ACCESS
- ASCENT MATED CONFIGURATION - LOADS, CG, TVC
- AERO CONFIGURATION
- GROUND MATING

HLLV
Design Concept

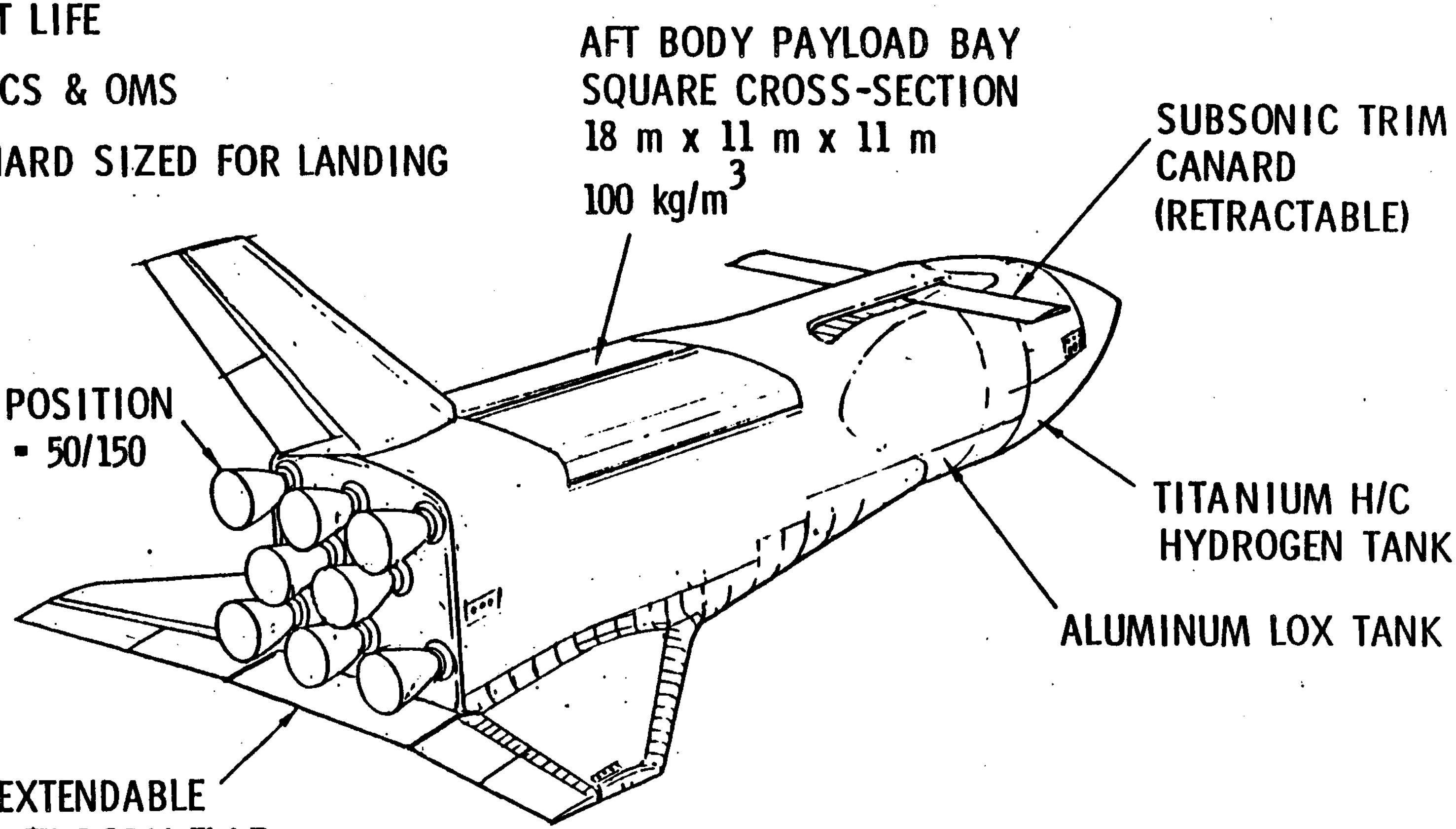
- PARALLEL BURN, CROSSFEED CONFIGURATION
- ALL PROPELLANT USED BY ORBITER ENGINES DURING BOOST CARRIED IN BOOSTER
- T/W @ L.O. = 1.3
- 2160 m/sec (7100 ft/sec) STAGING VELOCITY
- HEAT SINK BOOSTER
- ORBITER SSME NOZZLES EXTEND AT STAGING
- BOOSTER FLIES BACK TO LAUNCH SITE USING AIRBREATHER ENGINES



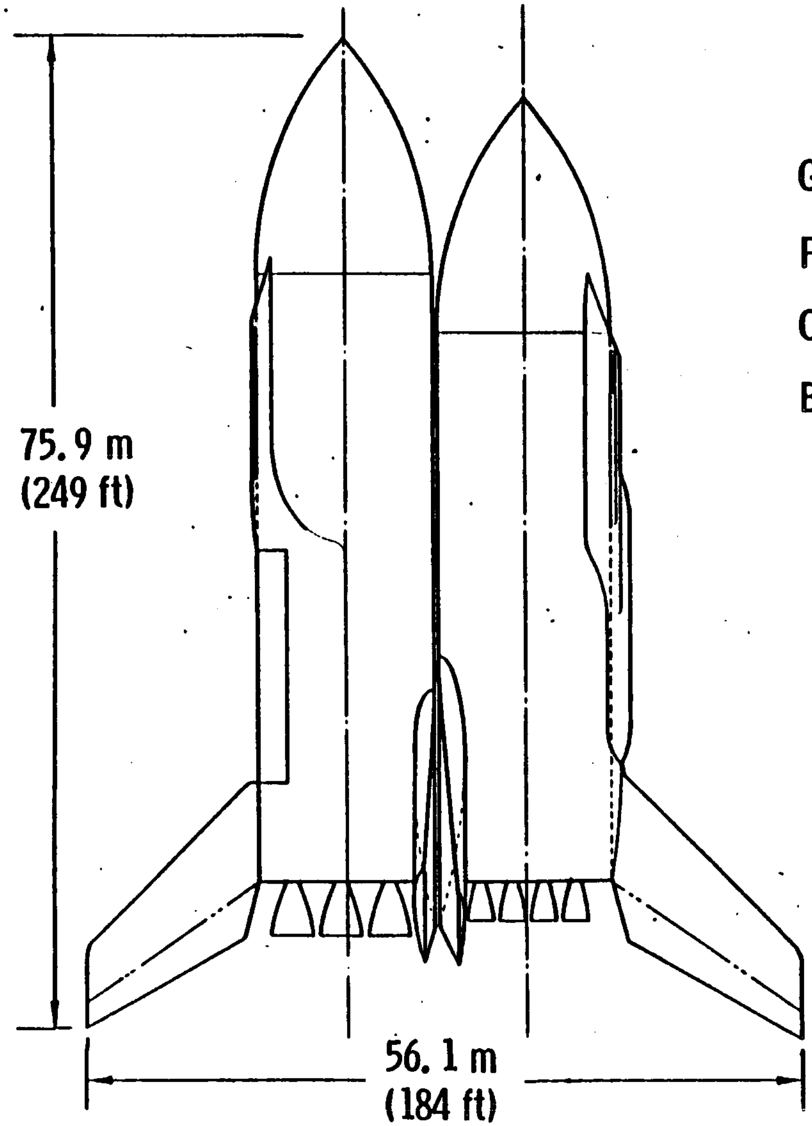
HLLV

Orbiter Design Concept

- ADVANCED COMPOSITE NON-PRESSURIZED STRUCTURE
- RSI TPS
- T/W = 1 AT STAGING
- 500 FLIGHT LIFE
- LO_2/LH_2 RCS & OMS
- WING/CANARD SIZED FOR LANDING



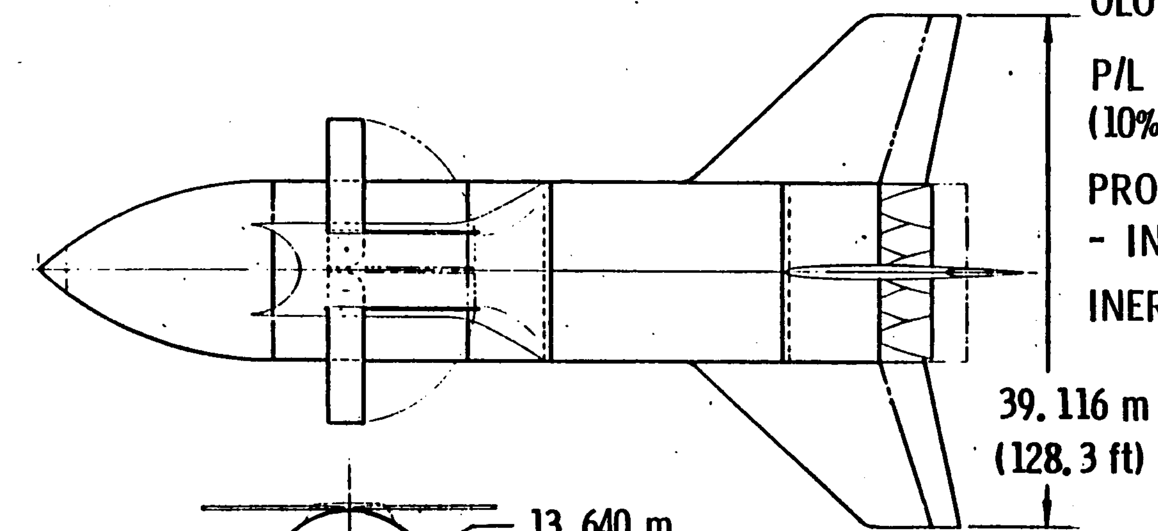
HLLV Configuration

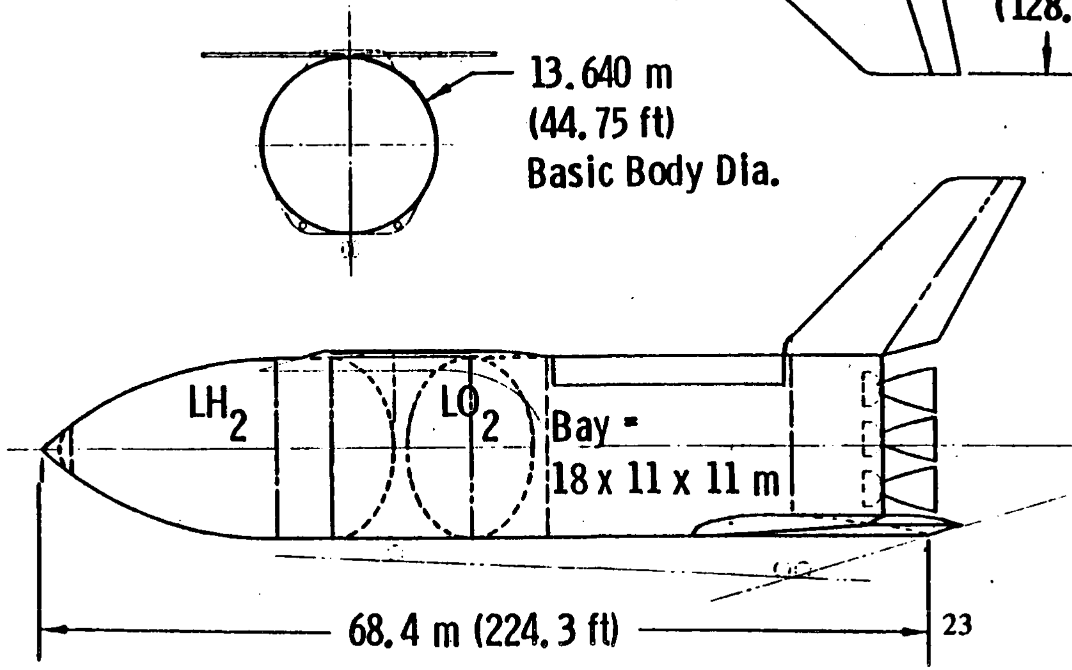


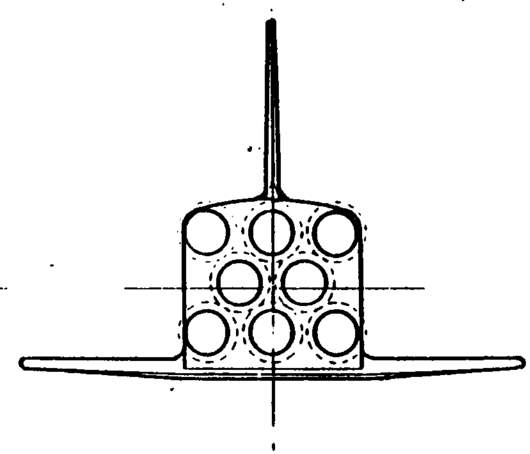
GLOW	5,047,619 KG	(11,130,000 LB)
P/L WT. (10% RETURN)	226,757 KG	(500,000 LB)
OLOW - EXCL. P/L	1,440,817 KG	(3,177,000 LB)
BLOW	3,380,045 KG	(7,453,000 LB)

HLLV Orbiter Configuration

OLOW	1,667,574 KG	(3,677,000 LB)
P/L WT. (10% RETURN)	226,757 KG	(500,000 LB)
PROP. WEIGHT - INCL. FPR	1,200,363 KG	(2,646,800 LB)
INERT WEIGHT	240,454 KG	(530,200 LB)



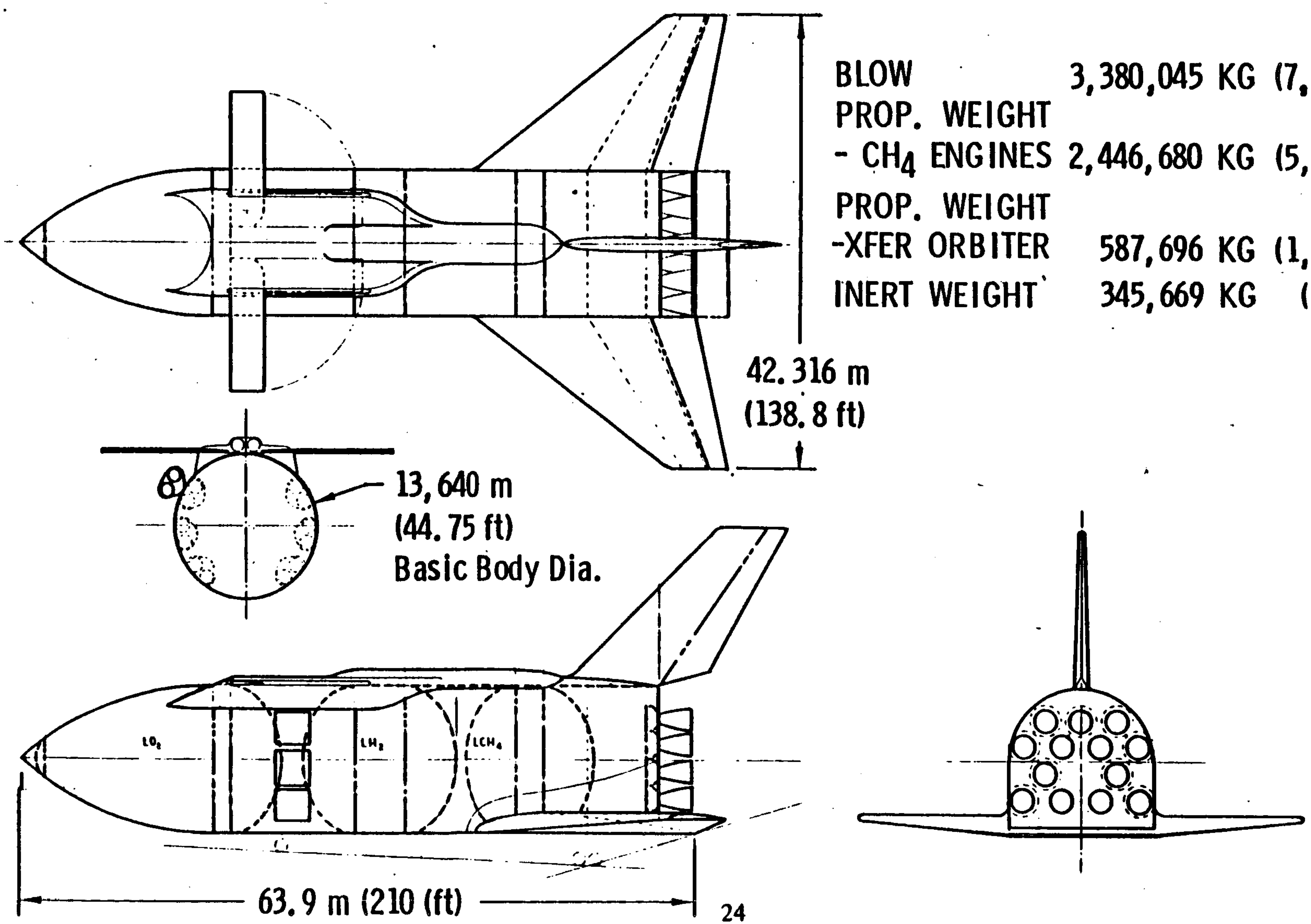




HLLV Booster Configuration

TR-27

BLOW	3,380,045 KG	(7,453,000 LB)
PROP. WEIGHT - CH_4 ENGINES	2,446,680 KG	(5,394,930 LB)
PROP. WEIGHT -XFER ORBITER	587,696 KG	(1,295,870 LB)
INERT WEIGHT	345,669 KG	(762,200 LB)



POTV – Design Requirements & Issues

REQUIREMENTS:

- SPACE BASED @ 500 KM
- GEO DESTINATION - EQUATORIAL
- 75% RETURN PAYLOAD
- TRIP TIME-T/W SUITABLE FOR MANNED MISSION
- 50 MISSION VEHICLE LIFE/10 MISSION ENGINE LIFE

ISSUES:

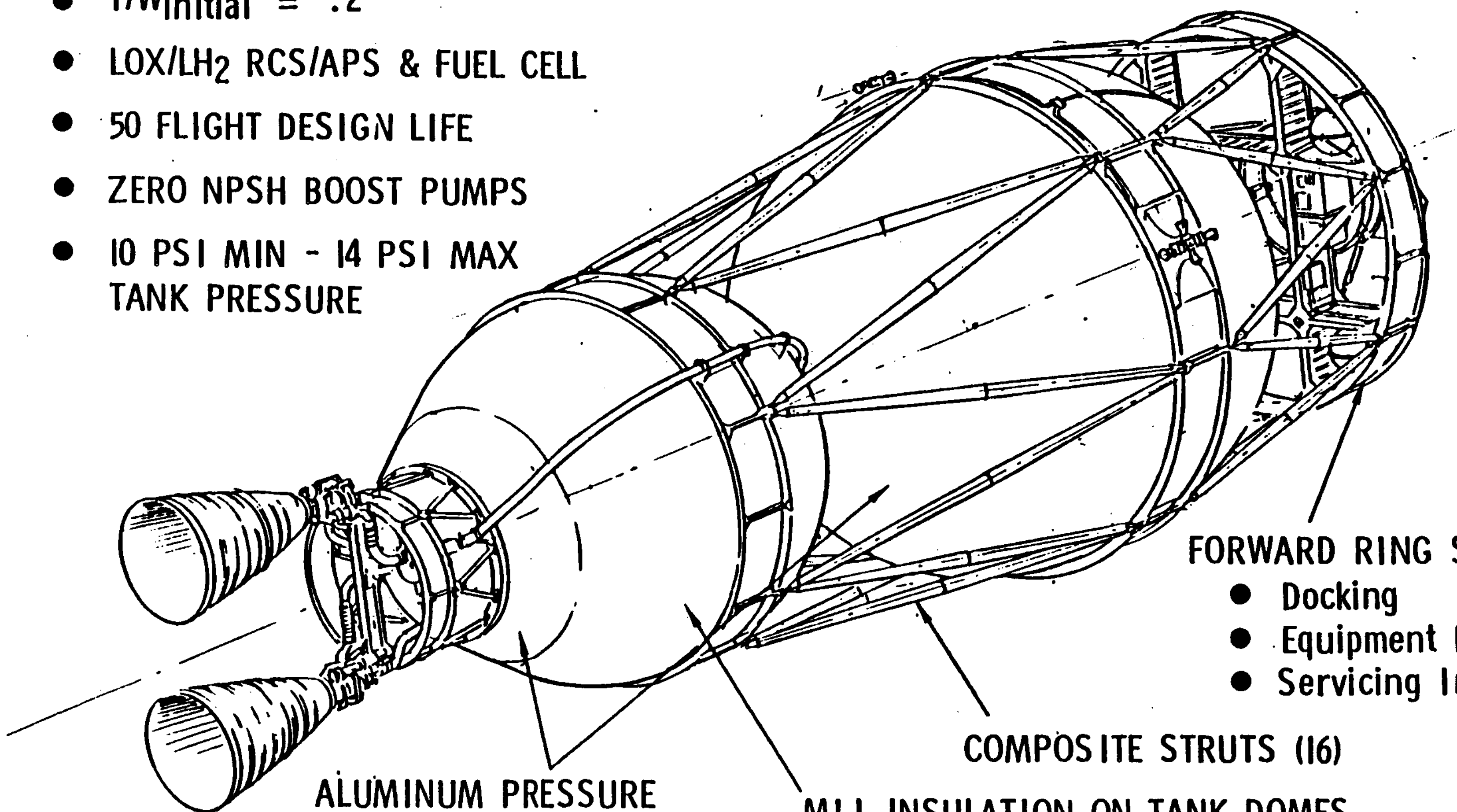
- SINGLE VERSUS TWO STAGE
- PAYLOAD SIZE
- SPACE BASED TECHNOLOGY

Space Basing

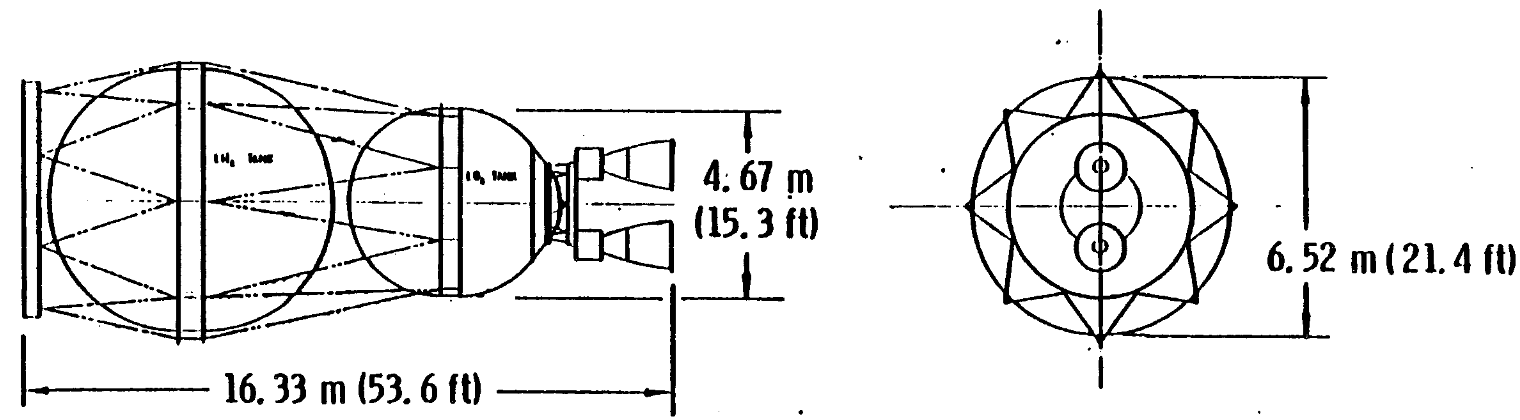
- PAYLOAD HANDLING
- PROPELLANT CONDITIONING, STORAGE & TRANSFER
- OTV SERVICE & MAINTENANCE INCLUDING ENGINE CHANGEOUT
- LCOTV SPACE FAB & ASSY
- REDUCED STRUCTURAL REQUIREMENTS ON OTV'S
- VEHICLE INTERFACE BURDEN

POTV – Design Concept

- "ASE" TYPE ENGINES X2 @ 20 K LBF, I_{sp} = 476 @ E = 400
- $T/W_{initial} \cong .2$
- LOX/LH_2 RCS/APS & FUEL CELL
- 50 FLIGHT DESIGN LIFE
- ZERO NPSH BOOST PUMPS
- 10 PSI MIN - 14 PSI MAX TANK PRESSURE



POTV Configuration



GROSS WEIGHT	96,839 KG (213,530 LB)
P/L WEIGHT (75% RETURN)	12,381 KG (27,300 LB)
PROP. - MAINSTAGE-INCL. FPR	78,413 KG (172,900 LB)
INERT WEIGHT	6,045 KG (13,330 LB)

T/W @ STARTBURN 0.187

LCOTV
Design Requirements & Issues

REQUIREMENTS:

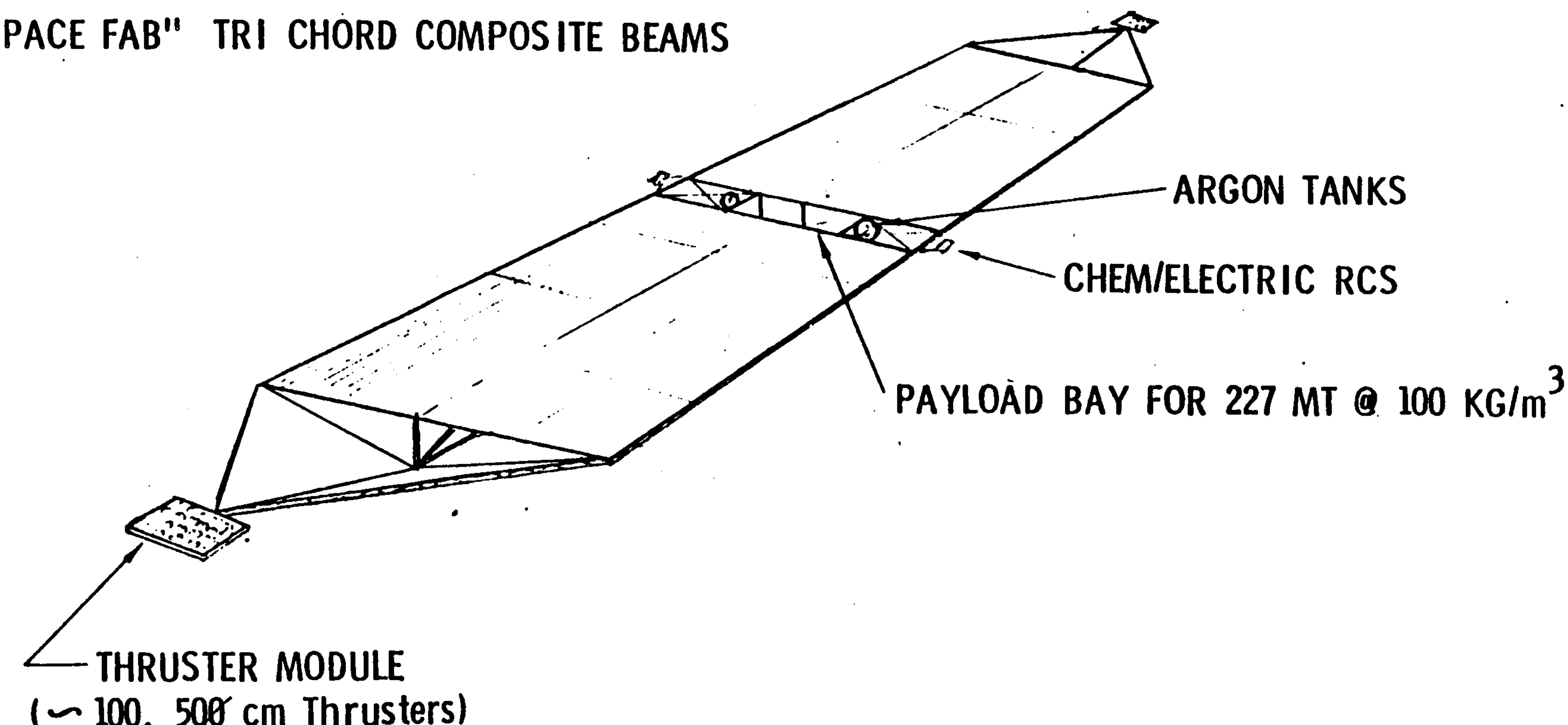
- PAYLOAD TO MATCH HLLV
- NO RETURN PAYLOAD
- NO TRIP TIME CONSTRAINT
- SPACE ASSEMBLED/SPACE BASED

ISSUES:

- VEHICLE CONFIGURATION
- I_S, TRIP TIME, NUMBER OF THRUSTERS, BEAM CURRENT
- EFFECTIVE THRUST USAGE

LCOTV - Design Concept

- ARGON FUELED ION THRUSTERS (I_S = 8,000)
- T/W 5×10^{-5} (180 day trip time)
- CONCENTRATION RATIO = 1, SIMPLE SOLAR ARRAY
- "SPACE FAB" TRI CHORD COMPOSITE BEAMS
- "HIGH" ASPECT RATIO, MAIN AXIS POP



LCOTV Configuration

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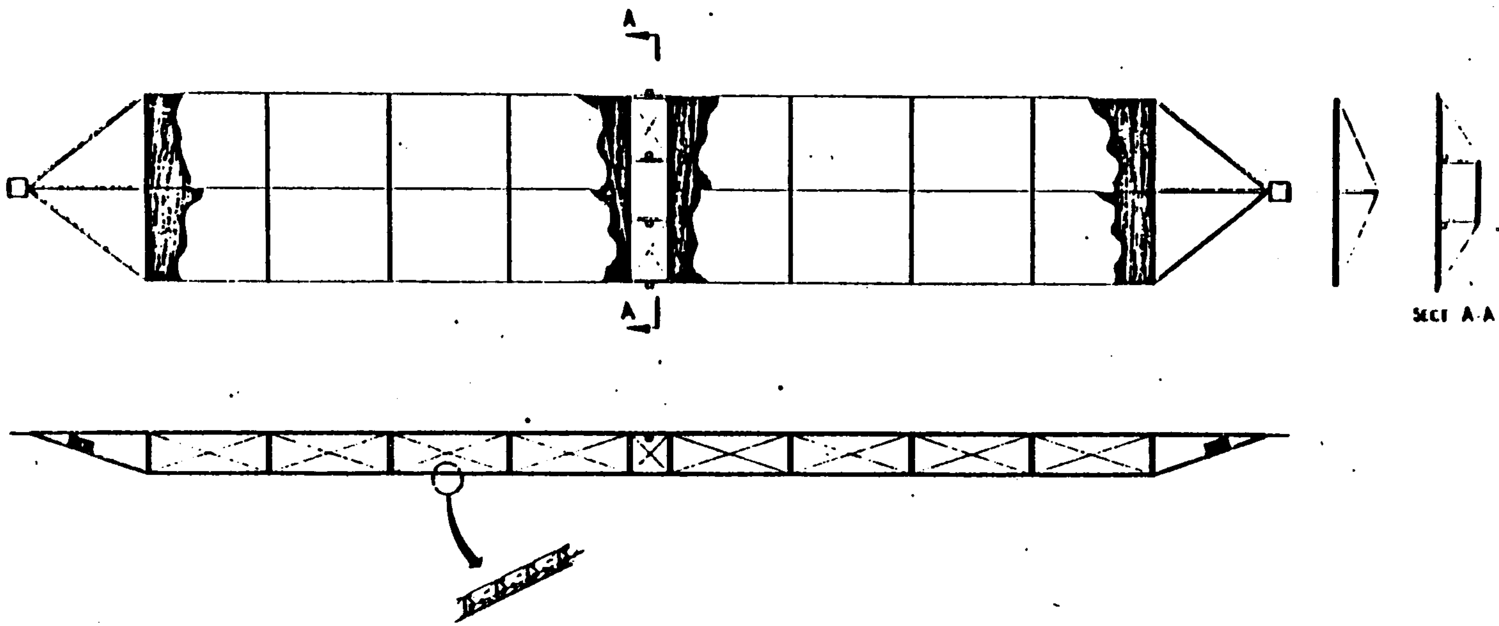


GROSS WEIGHT	=	305, 330 kg (673,253 lb)
P/L WEIGHT (0% RETURN)	=	226, 757 kg (500,000 lb)
ARRAY AREA	=	52,900 m^2
ARRAY INITIAL POWER OUTPUT	=	9.878 megawatts
NO. OF THRUSTERS	=	220
TOTAL THRUST	=	153 Newtons (34 lb)
T/W	=	5.1×10^{-5} g's

Mission Requirements

SCENARIO: 1990-2005 TIME FRAME - EARLY SPACE INDUSTRIALIZATION LEADING TO SPS DEPLOYMENT

VEHICLE	MISSION ROLE		REQUIREMENTS (MIN)		REQUIREMENTS (MAX)
PRIORITY CARGO OTV	• GEO MANNED SORTIES	TOTAL FLTS -	1,319		
	• GEO SATELLITE	ANNUAL FLT RATE	32	→	154
	• CREW TRANSFERS	ANNUAL PAYLOAD	0	→	853 MT
PRIORITY CARGO LAUNCH VEHICLE	• POTV PAYLOADS	TOTAL FLTS -	2,888		
	• LEO SATELLITES	ANNUAL FLT RATE	108	→	252
	• CREW TRANSFERS	ANNUAL PAYLOAD	259 MT	→	1,352 MT
LARGE CARGO OTV	• LARGE UNMANNED CARGO TO GEO	TOTAL FLTS -	56		
		TOTAL PAYLOAD -	29, 860 MT		
		ANNUAL FLT RATE	1	→	13
		ANNUAL PAYLOAD	33 MT	→	3010 MT
HEAVY LIFT LAUNCH VEHICLE	• LCOTV PAYLOADS.OTV DELIVERY & REFURB	TOTAL FLTS -	609		
		TOTAL PAYLOAD -	138,018 MT		
	• OTV PROPELLANT	ANNUAL FLT RATE -	15	→	74
	• HEAVY LIFT TO LEO	ANNUAL PAYLOAD -	3,400 MT	→	16,686 MT

Fleet Sizing

GROUNDRULES:

- BASELINE 2 SHIFTS/DAY, 5 DAYS/WEEK, 50 WEEKS/YR = 4000 HR/YR
- 3 SHIFTS/DAY AVAILABLE ON TEMPORARY BASIS
- MAX. VEHICLE FLIGHT RATE/YR = 4000/VEHICLE TURNAROUND TIME
- FLEET SIZED TO MEET MAXIMUM YEARLY FLIGHT RATE WITH AVAILABLE VEHICLES (EXCLUDES VEHICLES BEING OVERHAULED)
- FLEET ALSO SIZED TO MEET MAXIMUM FLIGHT RATE WITH ONE VEHICLE UNDERGOING UNSCHEDULED MAINTENANCE FOR UP TO 3 MO'S.

RESULTS:

	HLLV	SSTO	LCOTV	POTV
FLEET SIZE:	3	8	13	5
MAX. FLT RATE/YR:	74	252	13	154
TOTAL NO. FLTS:	609	2888	56	1319

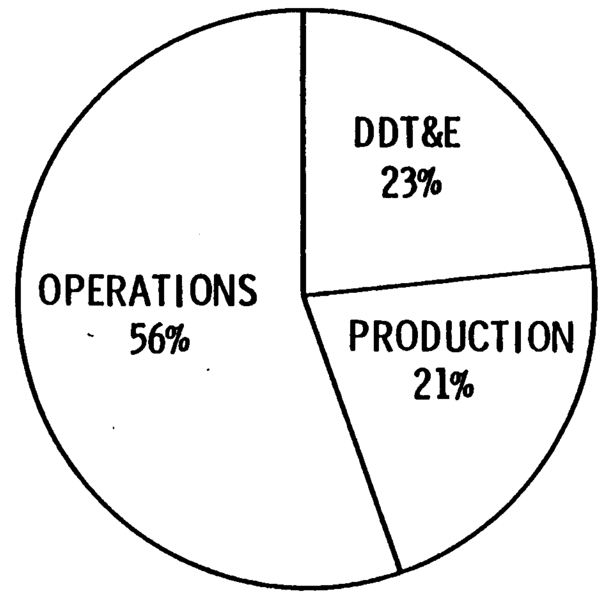
Costing

- METHODOLOGY
  - DDT&E & TFU DEVELOPED USING BOEING PCM
  - OPERATIONS LABOR COSTS BASED ON HHLV, SPS & SHUTTLE DERIVATIVE STUDIES

- KEY GROUNDRULES
  - 1977 DOLLARS
  - CONTRACTOR CHARGES WITHOUT FEE
  - ONLY PROGRAM SUPPORT BASED ON SHUTTLE USER CHARGES
  - INDIRECT COSTS BASED ON TYPICAL INDUSTRY CHARGES
  - PROPELLANT COSTS BASED ON JSC ESTIMATES
    - LH_2 = \$.731/lb LO_2 = \$.018/lb CH_4 = \$.188/lb

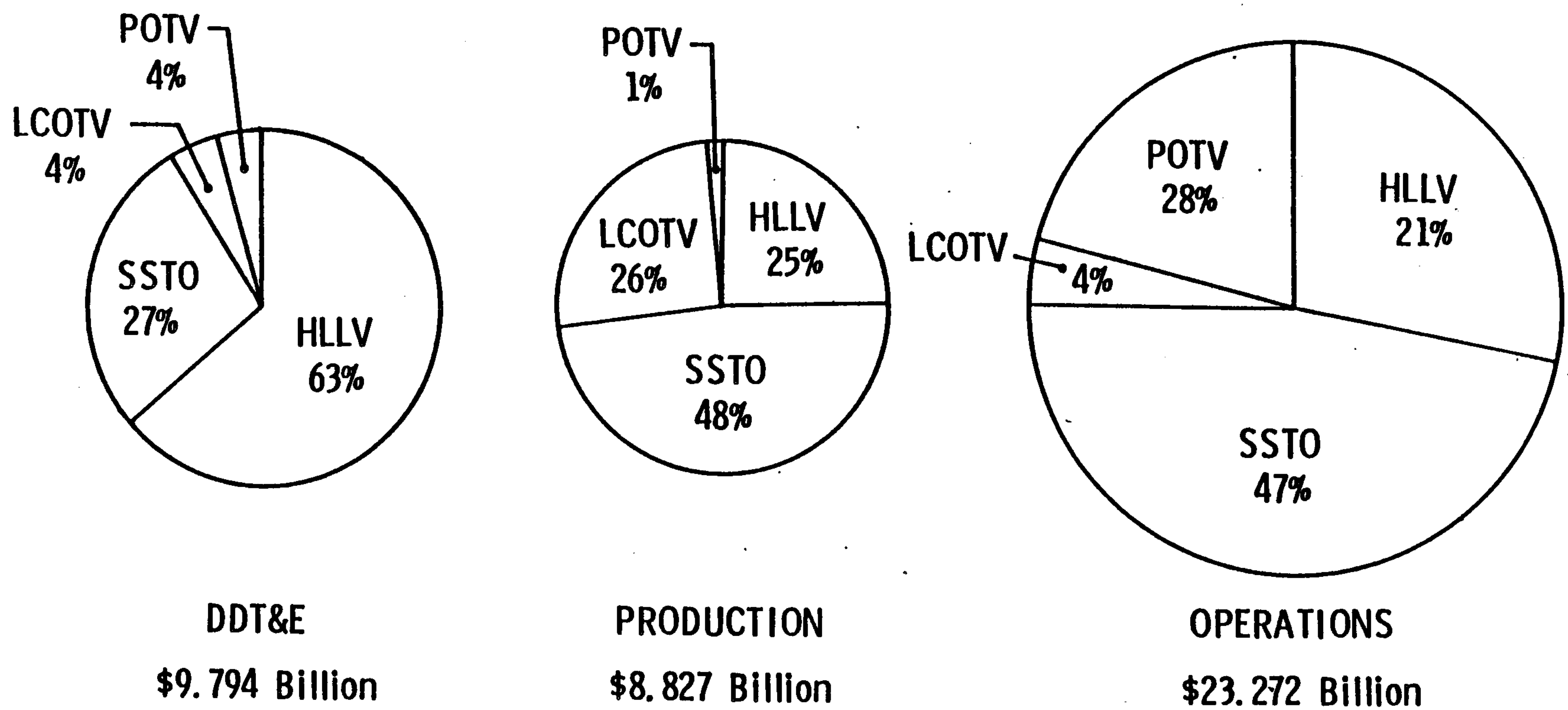
Total System
Cost Summary

PROGRAM PHASE	MILLIONS OF DOLLARS	
TOTAL PROGRAM	41,892.87	
DDT&E	9,794.35	
PRGM. MANAGEMENT		277.62
ENGINEERING		3,705.85
MANUFACTURING		4,390.29
TEST		1,420.59
PRODUCTION	8,827.00	
PRGM. MANAGEMENT		658.89
SYST. ENGINEERING		211.54
MANUFACTURING		7,956.56
OPERATIONS	23,271.52	
OPERATIONS SUPPORT		10,524.41
LAUNCH SUPPORT		12,747.12



TOTAL: $41.892 BILLION

System Costs – Another Slice



Findings

- GOOD REFERENCE VEHICLE SET AND DATA BASE
- SPACE BASING ATTRACTIVE FOR POTV
- SPACE BASED POTV → SINGLE STAGE
- LARGE SPACE BASED POTV CAN BE EFFICIENTLY OFFLOADED
- SHUTTLE CONSTRAINT ON POTV → SMALL PENALTY
- PRIORITY CARGO P/L OPTIMIZATION SENSITIVE TO SSTO & MISSION REQM'TS
- PRIORITY CARGO COSTS LARGE SHARE OF TOTAL
- DELTA V FOR 500 KM MISSION TOUGH ON SSTO WITH HIGH SENSITIVITY TO SIZE
- HLLV STILL EFFICIENT AT RELATIVELY LOW MISSION REQUIREMENTS
- CHEMICAL LCOTV BEATS SOLAR ELECTRIC IN THIS SCENARIO
- SOLAR ELECTRIC REQUIRES MISSION SCENARIO WHICH ALLOWS VEHICLE AMORTIZATION TO BEAT CHEMICAL
- OPEN ISSUES:
  - SPACE BASE DEFINITION/COSTS
  - ALTERNATE VEHICLE CONFIGURATIONS

Accelerated Technology Summary

ACCELERATED TECHNOLOGY ITEMS	SSTO	HLLV	POTV	LCOTV
IMPROVED SSME	X	X		
DUAL FUEL/DUAL EXPANDER ENGINE	X	X		
ALTERNATIVE OTV ENGINE			X	
SLUSH PROPELLANTS	X	X		
INTEGRATEDLOX/LH_2 SUBSYSTEMS	X	X	X	
IMPROVED AVIONICS	X	X	X	
COMPOSITE STRUCTURES	X	X		
METALLIC TPS	X	X		
CCV CONFIGURATIONS	X	X		
SILICON VS GaAs SOLAR ARRAY				X
ION THRUSTER OPTIONS				X
DIRECT POWER PROCESSING				X

Accelerated Technology
Long Life SSME

- LIFE IMPROVED TO 250 CYCLES
- NO PERFORMANCE IMPROVEMENT
- NO IMPACT ON WEIGHT/GEOMETRY
- DDT&E = $370 M
- SAVINGS

  SSTO - $1261 M
  HLLV - $ 474 M

- FINDINGS:
  - GOOD BUY FOR SSTO IF NO DUAL/FUEL/DUAL EXPANDER DEVELOPMENT
  - NOT JUSTIFIED FOR HLLV

Accelerated Technology
Dual Fuel/Dual Expander Engine

- DUAL FUEL/DUAL EXPANDER — A COMPLEX, HIGH PRESSURE ENGINE THAT CAN OPERATE IN TWO MODES:

  A) BOOSTER MODE BURNING TWO FUELS AT MODERATE Isp AND HIGH THRUST

  B) UPPER STAGE MODE BURNING HYDROGEN WITH HIGH EXPANSION RATIO (HIGH Isp) AND REDUCED THRUST

MODE I:	SEA LEVEL	VACUUM
Thrust (lb)	1,150,000	1,275,200
Isp	352.2	390.5
ε	60.5	60.5

MODE II:		
Thrust (lb)	——	409,900
Isp	——	459.8
ε	——	127

CHAMBER PRESSURES: HYDROCARBON - 6000 PSI HYDROGEN - 3000 PSI

Weight (lbs)	9700
Length (inches)	158
Exit Diameter (inches)	105

COSTS: \$1.22 BILLION DDT&E; \$18.5 MILLION TFU

Accelerated Technology
Dual Fuel/Dual Expander Engine

- KEY ADVANTAGE IS THRUST-TO-WEIGHT RATIO & COSTS FOR DUAL FUEL PROPULSION

		DF/DE	CH_4/SSME PAIR
T/W	MODE 1 (S.L)*	118.6	92.2
	MODE 2 (VAC)	42.3	34.8
	COSTS (TFU)	\$18.5 Million	\$24.3 Million

* Sizing point ~ 30% improvement in engine weight
(However, in a one-on-one comparison with CH_4 engine -10% disadvantage

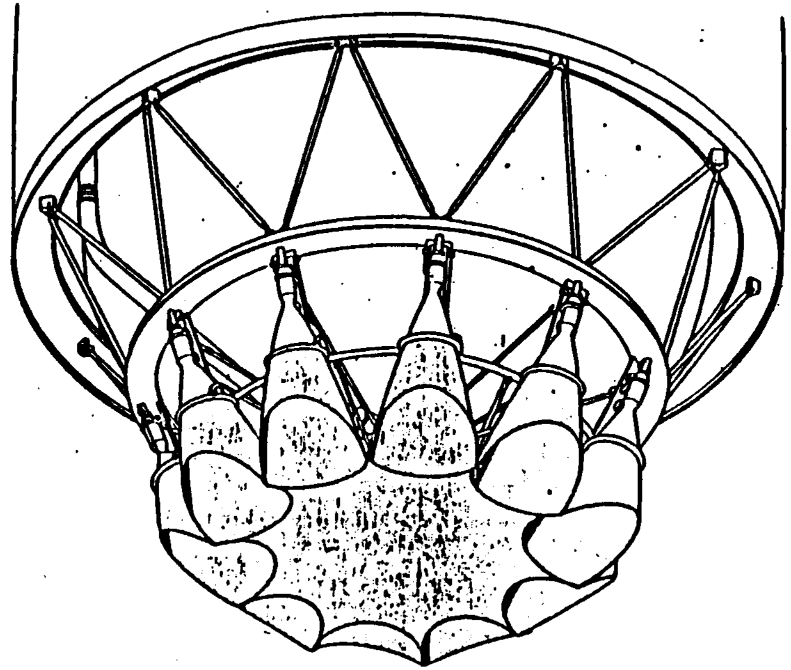
- COST BENEFITS

SSTO	\$2.067 Million (Net, includes DDT&E)
HLLV	\$ 531 Million*

* Net loser by \$687 million if DDT&E included.

- FINDINGS
  - BEATS A PAIR OF ENGINES (CH_4 + SSME) ON ALL COUNTS.
    PERFORMANCE - COST - WEIGHT
  - LOSES ON A ENGINE-TO-ENGINE BASIS ON ALL COUNTS
    - NOT JUSTIFIABLE FOR TWO STAGE SYSTEM

Accelerated Technology
Alternate OTV Engine



- PLUG CLUSTER CONCEPT

THRUST	—	40,000 lbs
Isp	—	466.9
WEIGHT	—	1267 lbs
INSTALLED WEIGHT DELTA		+173 lbs
CHAMBER PRESSURE		500 psi
ε	—	600
LIFE	—	1200 cycles
TFU COST	—	$.8 Million
DDT&E COST	—	125 Million

- COST IMPACT

  INCREASE OF 2 MILLION LCC

- FINDINGS
  - A COST PUSH
  - ADVANTAGES

    LENGTH (NOT A SPACE BASED ISSUE), LOW THRUST CAPABILITY, REDUNDANCY, MAINTAINABILITY

Accelerated Technology
"ASE" Type or New OTV Engine

- "ASE" TYPE OR NEW OTV ENGINE WAS ASSUMED AS NORMAL GROWTH
- IF RL10 IIB HAD BEEN CALLED NORMAL:

	RL10 IIB	"ASE" TYPE ENGINE
THRUST	15,000 LB	20,000 LB
CHAMPER PRESSURE	400 PSI	2,000
AREA RATIO	205	400
I_{SP}	457	473
WEIGHT	442 LB	454
LIFE	190 CYCLES	60
TFU COST	$1.25	$1.83 M
DDT&E COST	$50	$250 M

- COST BENEFIT OF NEW ENGINE

  $305 MILLION (5% of LCC)

- FINDINGS

  RL10 DERIVATIVE COULD BE A GOOD BUY IN A REDUCED MISSION MODEL

Accelerated Technology
"Slush" Propellants

- SLUSH HYDROGEN ONLY:
  - "SLUSH" LOX WOULD REQUIRE INSULATED TANK
  - ALL LOX TANKS ARE SMALL AND HAVE HIGH VOLUMETRIC EFFICIENCY
  - LOX TANK WEIGHTS MORE SENSITIVE TO PROPELLANT MASS (INSTEAD OF DENSITY) SINCE INERTIAL LOADS RATHER THAN BURNOUT PRESSURE SIZE TANK WALLS.
  - SIGNIFICANT GROUND FACILITY IMPACT FOR "SLUSH" LOX AS COMPARED TO SLUSH LH_2

- SLUSH HYDROGEN IMPACT:

		WGT (LB)	LENGTH (INCHES)
SSTO:		-3860	- 220
HLLV: -	ORBITER	-3316	- 94
	BOOSTER	- 160	- 61

- COST IMPACTS:

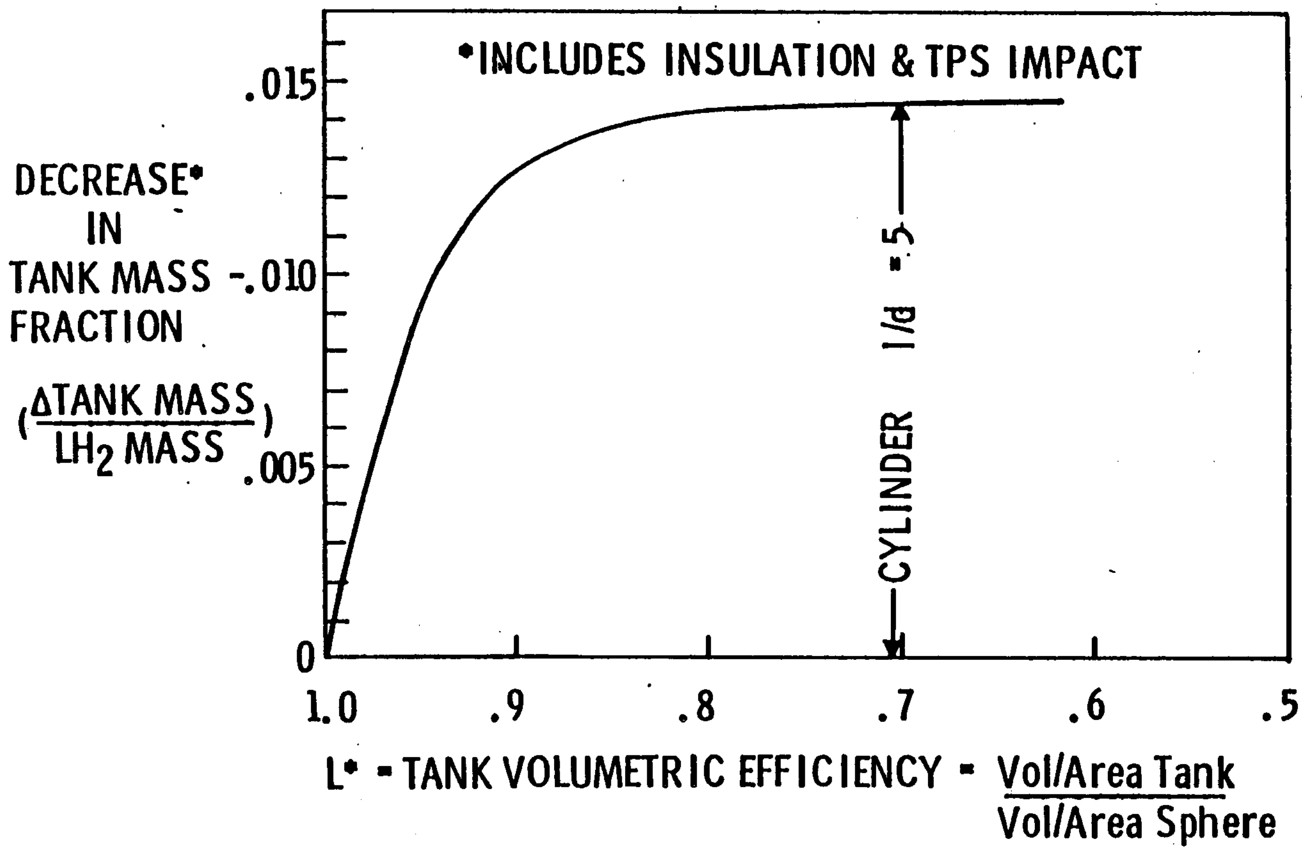
  (PROPELLENT COST DELTA OF 25% BASED ON LeRc/MARTIN STUDY)

  SSTO $-300 MILLION (INCLUDES +$50M DDT&E)

  HLLV $+67.8 MILLION (NO DDT&E DELTA)

Accelerated Technology
Slush Propellants

TR-98



FINDINGS: PAYS ONLY FOR VEHICLES WITH TANKS OF LOW VOLUMETRIC EFFICIENCY (AERO-SHAPED) AND SIGNIFICANT HYDROGEN VOLUME.

Accelerated Technology
Integrated "Oxygen-Hydrogen" Subsystems

- NORMAL GROWTH = INDEPENDENT OXYGEN/HYDROGEN FUELED SUBSYSTEMS
- ACCELERATED TECHNOLOGY = SYNERGISTIC INTEGRATION OF THESE SUBSYSTEMS
  - COMMON STORAGE TANKS
  - COMMON SERVICE INTERFACE
  - COMMON RESERVES

(Design Price = Long Feed Lines, Different Conditioning Reqm'ts, Conflicting Duty Cycles, Cascading Failure Modes, Interrelated Development Planning/Risks)

- IMPACT

		Dry Wgt Δ (lb)	Propellant Δ (lbs)	Δ Cost $M
SST		-2090	-928	-434
HLLV	Booster	-1205	-189	-30
	Orbiter	-2336	-1192	
POTV		-119	-132	-102

- FINDINGS
  - MODERATE PAYOFF BASED ON COST BENEFITS
  - SIGNIFICANT OPERATIONAL ADVANTAGE TO SPACE-BASED POTV - SINGLE POINT REFUELING

Accelerated Technology
Avionics

- CHARACTERISTICS:

	% REDUCTION WEIGHT	% REDUCTION POWER
POTV	20%	17%
SSTO, HLLV	25%	15%

NO COST IMPROVEMENT/NO DDT&E PENALTY
NO RELIABILITY IMPROVEMENT

- COST BENEFITS:

POTV	$18.5 MILLION
SSTO	$411.0 MILLION
HLLV	$9.2 MILLION

- FINDINGS:
  - IMPROVEMENT ABOVE NORMAL GROWTH MARGINAL EXCEPT FOR SSTO
  - RELIABILITY IMPROVEMENT COULD BE MORE SIGNIFICANT

Accelerated Technology
Composite Structures

- CHARACTERISTICS:
  - ALL COMPOSITE DESIGN IS METAL SUBSTITUTION FOR NORMAL GROWTH IMPROVED WGT FRACTION BY 10% (TO 40% TOTAL REDUCTION)
  - EXPANDED APPLICATION TO PROPELLENT LINES
  - REDUCED FAB AND DDT&E COSTS TO "STATE OF ART" LEVELS
  - IMPROVED PROPERTIES NOT CONSIDERED
- COST BENEFIT:

  SSTO — $3,112 MILLION
  HLLV — 986 MILLION

- FINDINGS:

  MOST IMPORTANT TECHNOLOGY AREA!

Accelerated Technology
Metallic TPS

- CHARACTERISTICS

  TEMP LIMITS OF 1600^{0}F — 1800^{0}F (LRSI SUBSTITUTE)
  300 ENTRY LIFE
  NO WEIGHT REDUCTION ASSUMED
  INSTALLED UNIT COST UP BY A FACTOR OF 2

- OPERATIONAL ASSUMPTIONS

  POST FLIGHT TPS INSPECTION REDUCED BY 50%
  PER FLIGHT TPS SPARES & TURNAROUND REPAIR REDUCED BY 40%
  REDUCED OVERHAUL COSTS
  TOTAL TURNAROUND FLOW TIME NOT AFFECTED

- COST BENEFIT:

SSTO	\$76 MILLION	NO DDT&E DELTA \$
HLLV	\$36 MILLION	

- FINDINGS:

  MARGINAL IF COST IMPROVEMENT ONLY JUSTIFICATION

Accelerated Technology
CCV Configuration — No Vertical Tail

• CONFIGURATION REVISIONS (BASED ON LaRc STUDIES)	NORMAL GROWTH SSTO WGT Δs (lb)
• REMOVE VERTICAL TAIL, ASSOCIATED FLT. CONTROLS AND BODY TIE IN.	- 15,115
• ADD WING TIP AERO TRIM SURFACES	+ 1,600
• ADD SUBSONIC FORWARD YAW SURFACE (RETRACTABLE)	+ 450
• ADJUST RCS FOR ADDITIONAL DUTY CYCLE & ALTITUDE REQM'T.	+ 500
• ADD LANDING CHUTE OR ALTERNATE SPEED BRAKE	+ 1,600
• ADJUST WING SWEEP FOR FAVORABLE CG IMPACT	- 1,374
• ADJUST GROWTH	- 1,234
TOTAL	- 13,570

- COST BENEFITS:

  SSTO - $1,652 MILLION
  HLLV - 412 MILLION

- FINDINGS:
  - IMPORTANT TECHNOLOGY AREA--IN ADDITION TO COST IMPACT THIS ITEM
    - MOVES CG FORWARD HELPING AERO PROBLEM IN PITCH AXIS
    - MAKES VEHICLE EASIER TO INSPECT, HANDLE & SERVICE
    - REDUCES IMPACT ON GROUND EQUIPMENT & FACILITIES
    - OPENS UP CONFIGURATIONS OTHER THAN 2-STAGE BELLY-TO-BELLY → X-FEED ON COLD SIDE

Accelerated Technology
Solar-Electric

- SOLAR ARRAY
  NORMAL GROWTH REVISED TO SILICON SOLAR ARRAY
    - 2 cm cell, 2 mil covers, 427 g/m^2, 197.7 W/m^2
- GAAS = ACCELERATED TECHNOLOGY
    - Thin Film, 2 mil covers, 384 g/m^2, 234.1 W/m^2
    - Cost up by 50%
- THRUSTER OPTIONS
    - 100 cm (39 kb), 80 amp beamp current
    - 100 cm with mission life (50 kg), 150 amp beam current
    - 100 cm with mission life and self-regulating characteristics (50 kg), 150 amp beam per unit
- POWER PROCESSING OPTION
    - Direct - Open Loop - Power from Array

Accelerated Technology
Solar-Electric

- COST SUMMARY ($ Millions)

	New Baseline	GaAs Replaces Silicon	Baseline with 100 cm Thrusters	Baseline w/100 cm Thruster w/Long Life	GaAs Array 100 cm Long Life Thruster Direct Power Processing
TOTAL LCC	3,276	3,334	3,492	3,348	3,236
DDT&E	388	394	463	617	596
PRODUCTION	1,930	2,009	1,964	1,963	1,911
OPERATIONS	958	930	1,063	767	728
PROPELLANT	98	92	97	96	88

- GaAs - reduced overal size offset by higher array cost.
- Thruster Improvements - improvements in thrust density/efficiency offset by increased DDT&E and higher production costs due to prod. rate sensitivity except for:

  self-regulating feature which allows open loop direct solar array power supply

- FINDINGS -

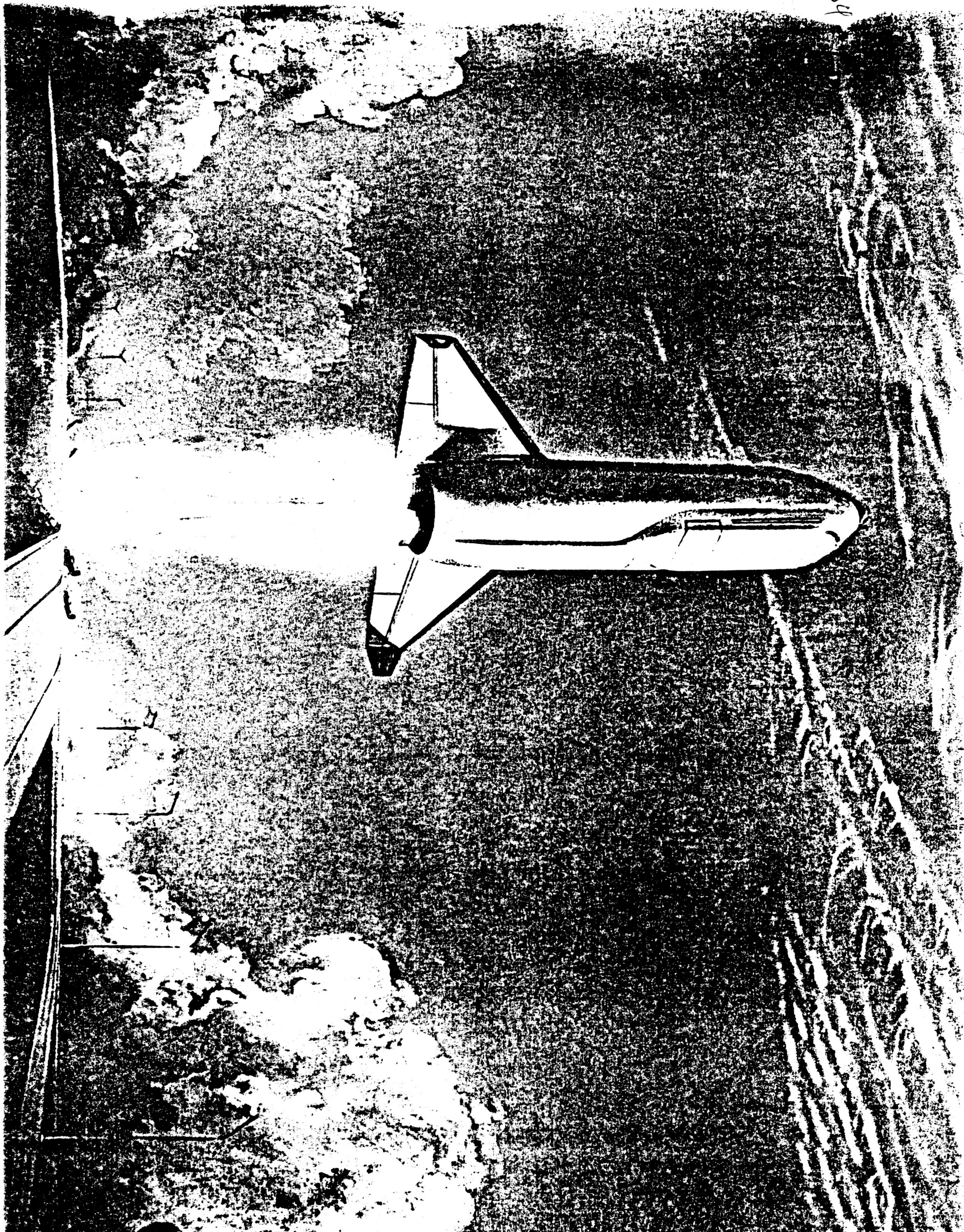
  This vehicle requires production oriented technology - not performance

Accelerated Technology
Life Cycle Costs Benefits Summary*

LIFE CYCLE COST DELTA $ x 10^6

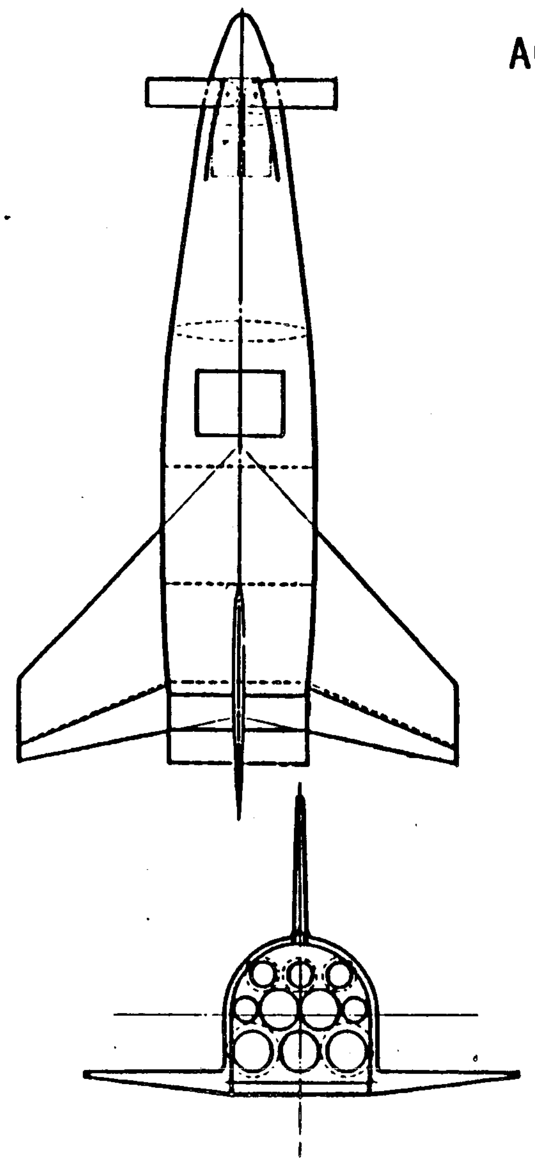
TECHNOLOGY	SSTO	HLLV	POTV	LCOTV	TOTAL
Composite Structures	-3112	-986	—	—	-4098
Dual Expander Engine	-2067	-531	—	—	-2598
Eliminate Vertical Tail	-1652	-412	—	—	-2064
Extended Life SSME	-1261	-474	—	—	-1735
Integrated Subsystems	-434	-30	-102	—	-566
Slush LH_2	-300	—	—	—	-300
Improved Avionics	-411	-9	-18	—	-438
Metallic TPS	-76	-36	—	—	-112
Plus Cluster Engine	—	—	(+2)	—	(+2)
Gallium Arsenide Array	—	—	—	(+58)	(+58)
100 cm Thruster	—	—	—	(+216)	(+216)
Long Life Thruster	—	—	—	(+72)	(+72)
Direct Power Processing	—	—	—	-386	-386

*These data reflect the benefit when each item is evaluated "by itself" on the reference vehicles.

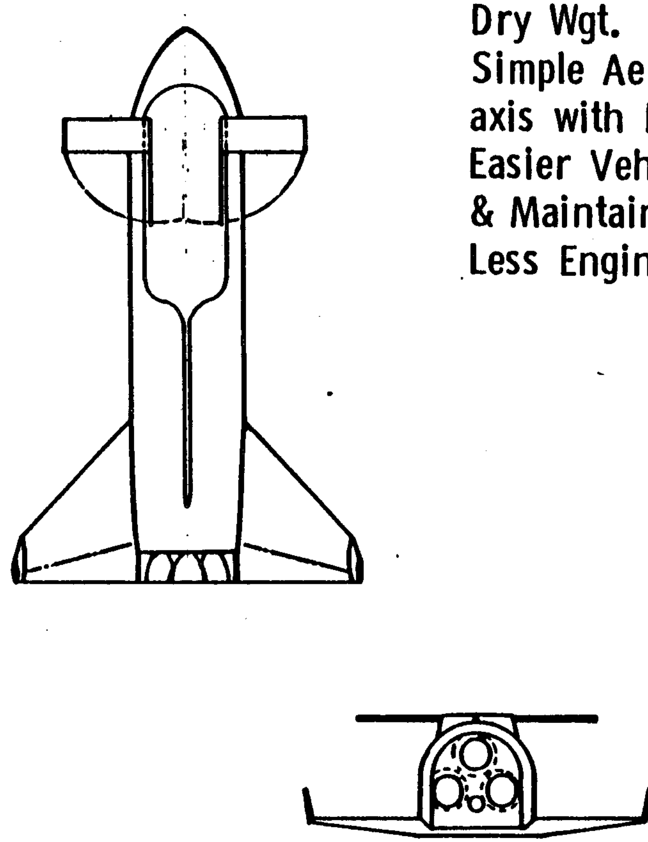


Accelerated Technology Impact On SSTO

NORMAL GROWTH

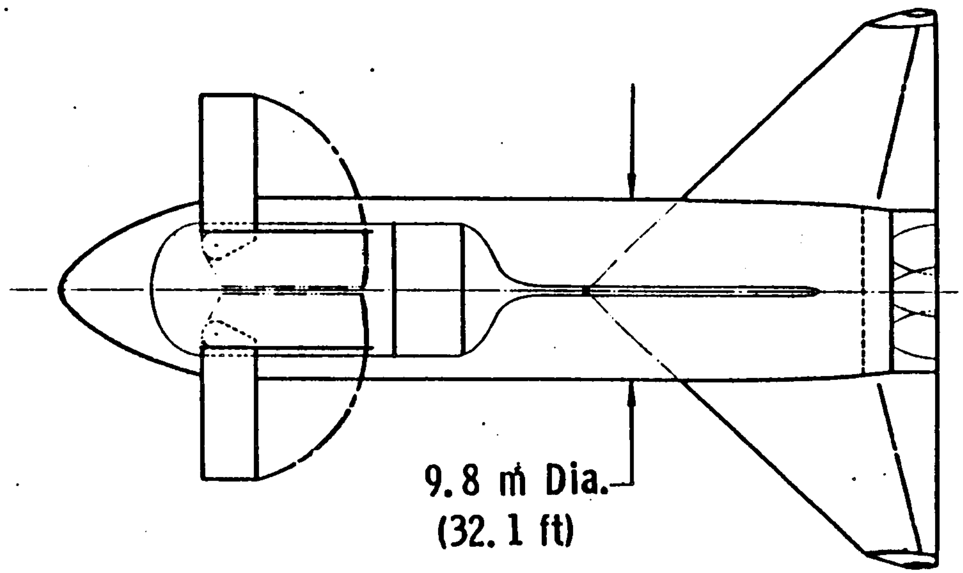


ACCELERATED TECHNOLOGY

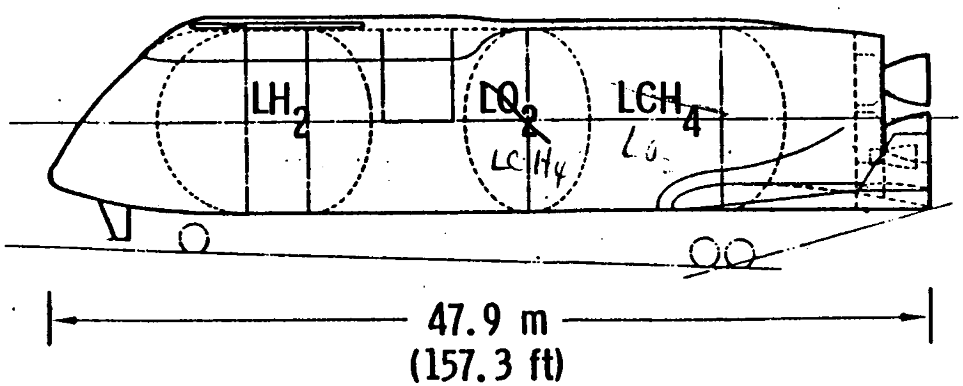


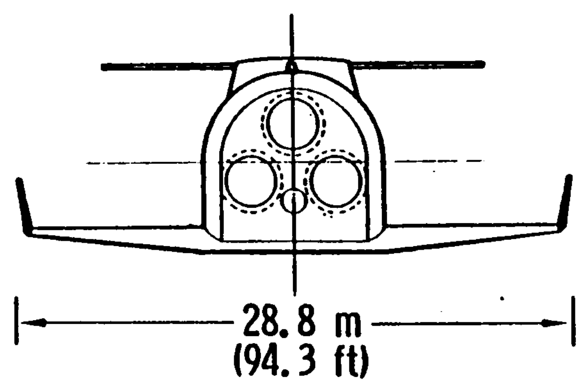
Glow Reduced by 46%
Dry Wgt. Reduced by 48%
Simple Aero Solution in Pitch axis with Forward CG
Easier Vehicle to Handle, House & Maintain
Less Engines - No.: 10 vs 3
Type: 2 vs 1

SSTO Configuration
ACCELERATED TECHNOLOGY



GLOW	1,203,628 KG	(2,654,000 LB)
P/L WT. (100% RETURN)	13,605 KG	(30,000 LB)
PRO. WT.-INCL FPR	1,065,216 KG	(2,348,800 LB)
INERT WEIGHT	124,807 KG	(275,200 LB)





SSTO — Characteristics & Weights
Accelerated Technology

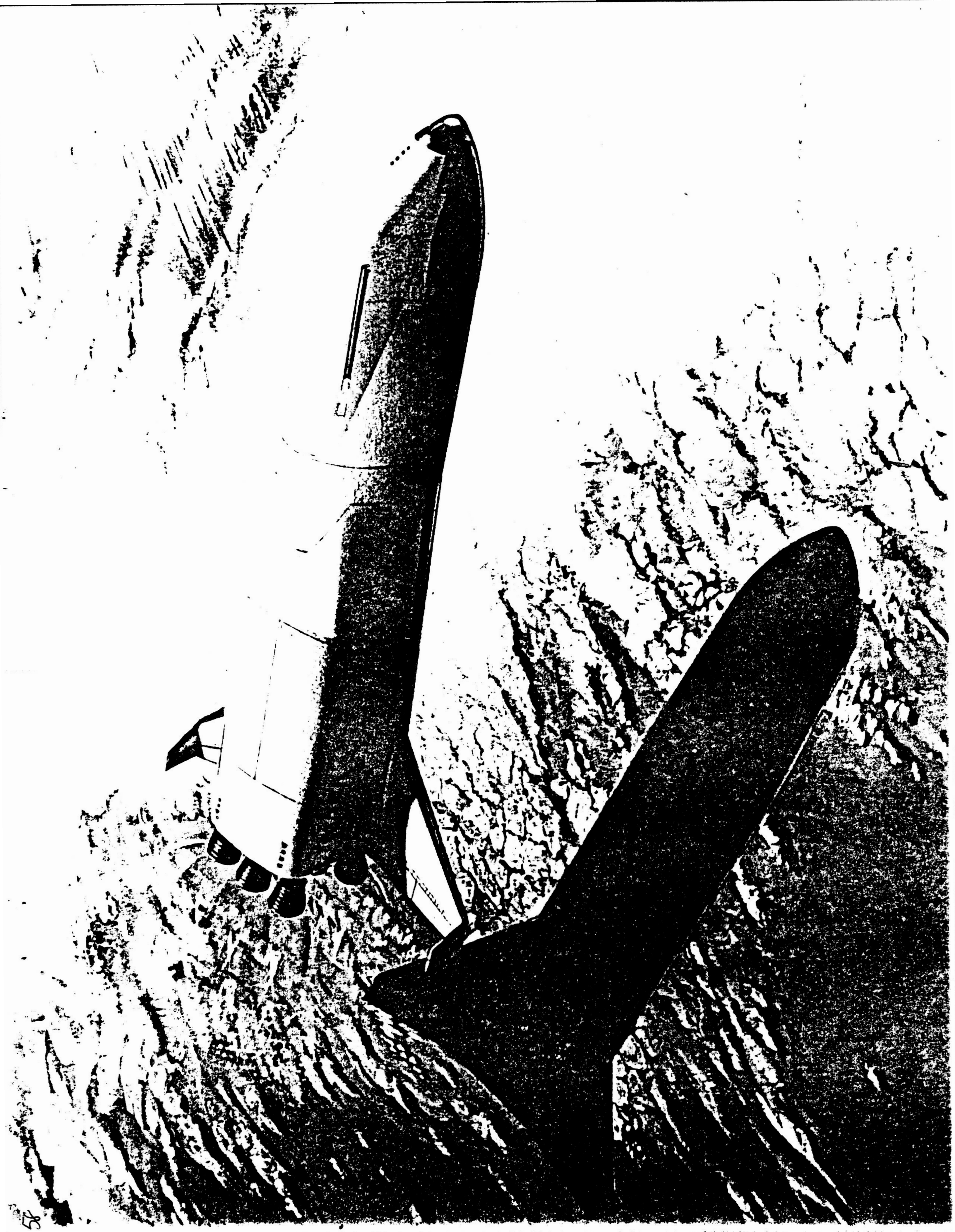
TR-37

AREAS	m^2	(FT^2)
WING - REFERENCE	331	(3,562)
WING - EXPOSED	169	(1,817)
ELEVON	39	(423)
CANARD	42	(450)
WING TIPLETS - EACH	8.8	(95)
YAW VENTRAL	2.2	(24)
BODY FLAP - STOWED	32	(342)
PLANFORM - FLAP	606	(6,520)
BODY BASE	82	(878)

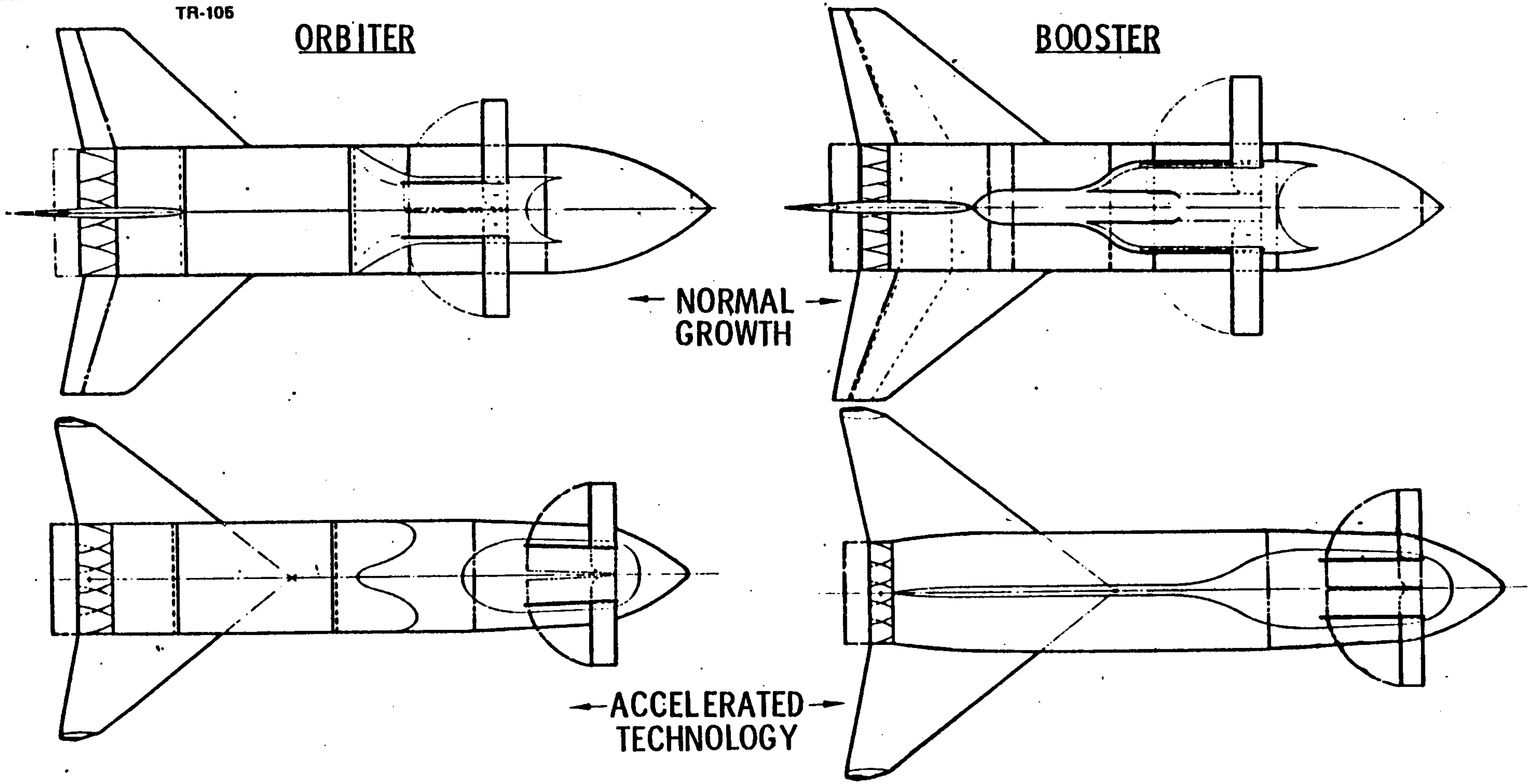
LONGITUDINAL CG'S	% B.L.
ENTRY	66.0
LANDING	66.1

LOADING	KG/m^2	(lb/ft^2)
ENTRY PLANFORM-FLAP EXT.	205	(42.0)
LANDING (REF. WING + CANARD)	331	(67.8)

WEIGHTS	KG	(LB)
AEROSURFACES	9,596	(21,160)
BODY	37,406	(82,480)
INDUCED ENVIRON. PROTECTION	14,875	(32,800)
LANDING & AUX. SYSTEMS	3,864	(8,520)
PROPULSION-ASCENT/RCS/OMS	22,381	(49,350)
SYSTEMS	6,939	(15,300)
MARGIN	10,540	(23,240)
DRY	105,601	(232,850)
PERSONNEL	667	(1,470)
PAYLOAD-ASCENT (100% RETURN)	13,605	(30,000)
RESIDUALS & RESERVES	3,524	(7,770)
INFLIGHT LOSSES	4,526	(9,980)
PROPELLANT - RSC	1,124	(2,480)
PROPELLANT - OMS	9,365	(20,650)
PROPELLANT-ASCENT INCL FPR	1,065,216	(2,348.800)
GROSS LIFTOFF	1,203,628	(2,654,000)

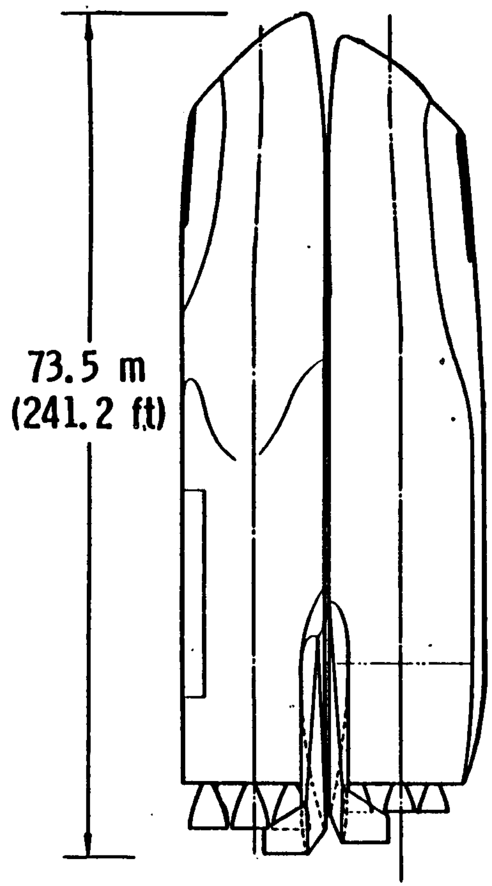


Accelerated Technology Impact On HLLV



- GLOW REDUCED BY ~ 16%
- DRY WEIGHTS REDUCED BY ~ 12%
- AERO SOLUTION W/O BALLAST
- EASIER VEHICLE TO HANDLE, HOUSE & MAINTAIN
- LESS ENGINES 21 VS 15

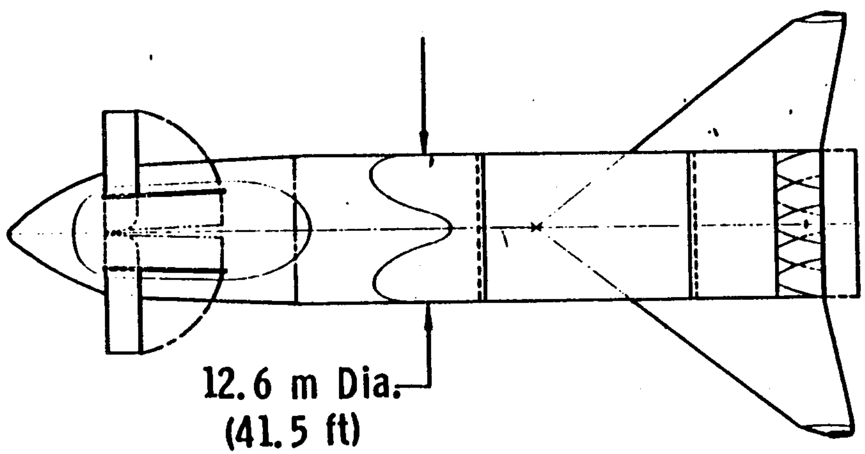
HLLV Configuration
ACCELERATED TECHNOLOGY



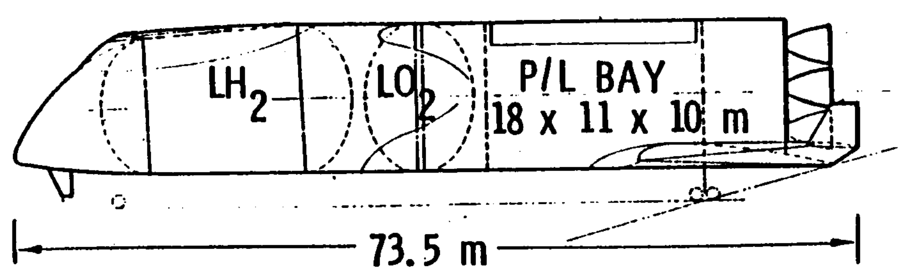
GLOW	4,225,080 KG	(9,316,300 LB)
P/L WT. (10% RETURN)	222,222 KG	(490,000 LB)
OLOW - EXCL. P/L	1,245,760 KG	(2,746,900 LB)
BLOW	2,757,098 KG	(6,079,400 LB)

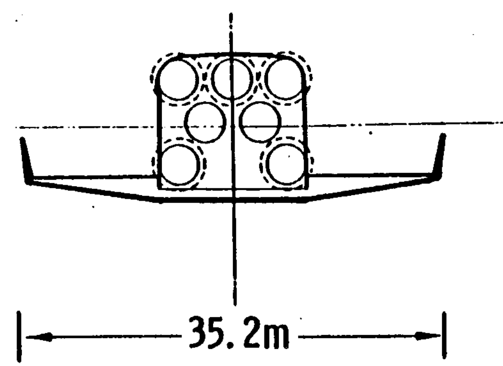
HLLV Orbiter Configuration
ACCELERATED TECHNOLOGY

TR-101



OLOW	1,467,982 KG	(3,236,900LB)
P/L WT. (10% RETURN)	222,222 KG	(490,000 LB)
PROP. WEIGHT (INCL. FPR)	1,048,254 KG	(2,311,400 LB)
INERT WEIGHT	197,506 KG	(435,500 LB)





HLLV
Orbiter Characteristics & Weights
ACCELERATED TECHNOLOGY

AREAS	M^2	(FT^2)
WING - REFERENCE	495	(5,327)
WING - EXPOSED	241	(2,593)
ELEVON	62	(662)
CANARD	42	(450)
WING TIPLETS - EACH	13	(142)
YAW VENTRAL	3.3	(35)
BODY FLAP - STOWED	54	(581)
BODY FLAP - EXTENDED	92	(989)
PLANFORM - FLAP EXTENDED	1,110	(11,949)
BODY BASE	143	(1,537)

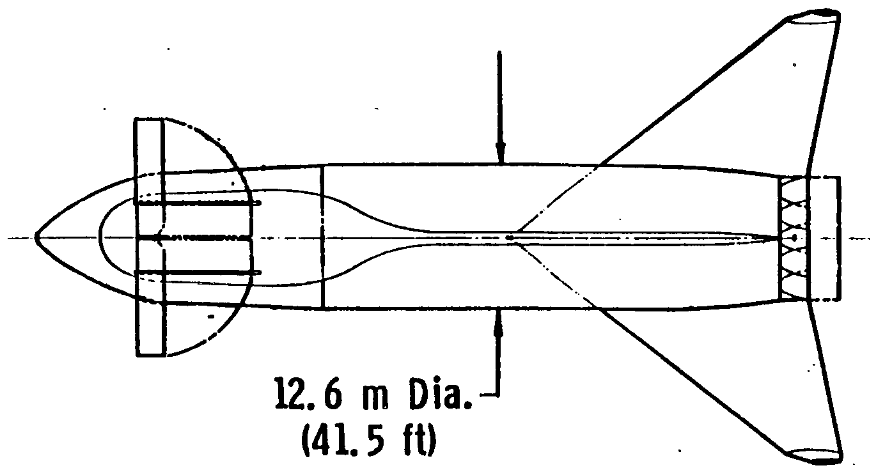
LONGITUDINAL CG'S	% B.L
ENTRY	71.8
LANDING	71.9

LOADING	KG/M^2	(LB/FT^2)
ENTRY PLANFORM-FLAP EXT.	175	(35.9)
LANDING (REF WING + CANARD)	360	(73.8)

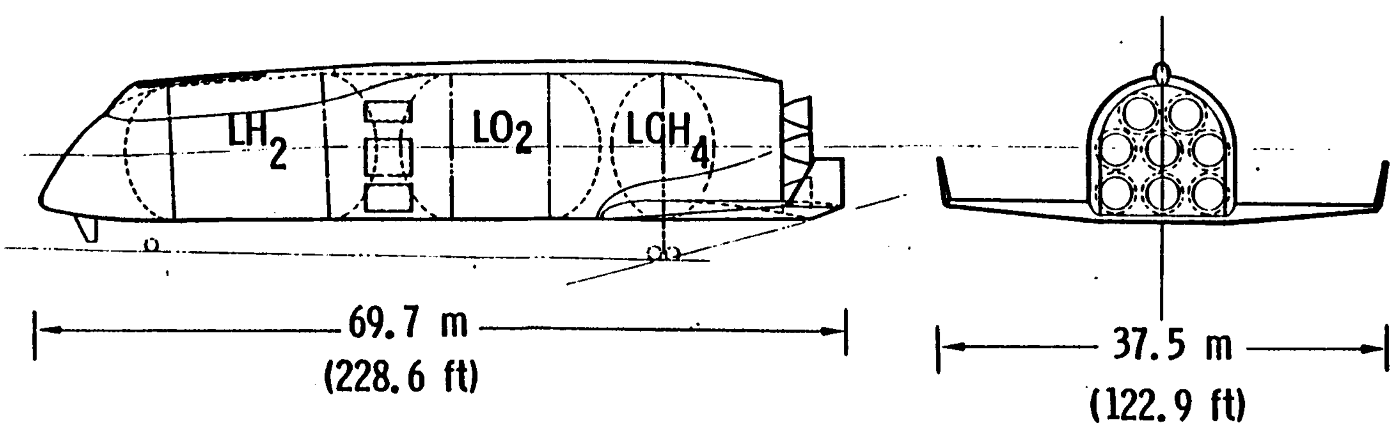
WEIGHTS	KG	(LB)
AEROSURFACES	15,243	(33,610)
BODY	62,131	(137,000)
INDUCED ENVIR. PROTECT.	21,088	(46,500)
LANDING & AUX. SYST.	7,002	(15,440)
PROPULSION-ASCENT/ RCS/OMS	36,658	(80,830)
SYSTEMS	10,835	(23,890)
MARGIN	13,610	(30,010)
DRY	166,567	(367,280)
PERSONNEL	--	(--)
PAYLOAD-ASCENT (10% RETURN)	222,222	(490,000)
RESIDUALS & RESERVES	4,240	(9,350)
INFLIGHT LOSSES	8,286	(18,270)
PROPELLANT - RCS	2,766	(6,100)
PROPELLANT - OMS	15,647	(34,500)
PROPELLANT-ASCENT INCL. FPR	1,048,254	(2,311,400)
OLOW	1,467,982	(3,236,900)

HLLV Booster Configuration

ACCELERATED TECHNOLOGY



BLOW	2,757,098 KG	(6,079,400 LB)
PROP. WEIGHT (ENGINES)	1,925,624 KG	(4,246,000 LB)
PROP. WEIGHT (XFER ORBITER)	544,626 KG	(1,200,900 LB)
INERT WEIGHT	286,848 KG	(632,500 LB)



HLLV

Booster Characteristics & Weights
Accelerated Technology

TR-36

AREAS	m^2	(Ft^2)
WING - REFERENCE	562	(6,046)
WING - EXPOSED	305	(3,279)
ELEVON	67	(725)
CANARD	37	(400)
TAIL	15	(161)
RUDDER/SPD BRAKE	3.7	(40)
BODY FLAP - STOWED	42	(456)
BODY FLAP - EXTENDED	42	(777)
PLANFORM - FLAP EXTENDED	1,070	(11,514)
BODY BASE	114	(1,232)

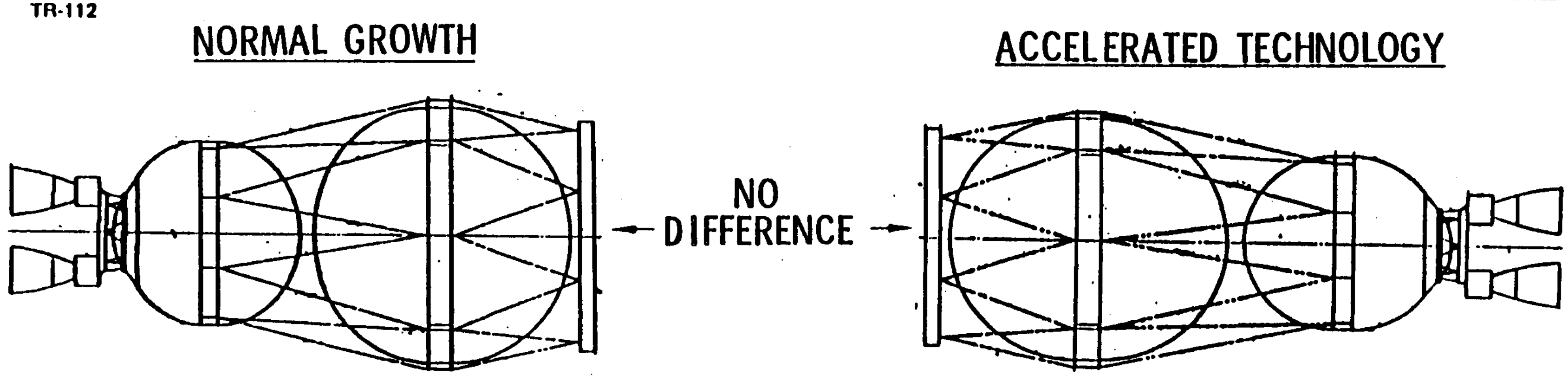
LONGITUDINAL CG's	% B.L.
ENTRY	71.1
LANDING	74.4

LOADING	kg/m^2	(lb/ft^2)
ENTRY PLANFORM-FLAP EXT.	245	(50.2)
START FLYBACK(REF. WING + CANARD)	436	(89.3)
LANDING (REF. WING + CANARD)	387	(79.2)

WEIGHTS	KG	(LB)
AEROSURFACES	24,372	(53,740)
BODY	75,011	(165,400)
INDUCED ENVIR. PROTECTION	9,043	(19,940)
LANDING & AUX. SYSTEMS	8,331	(18,370)
PROPULSION-ASCENT/ RCS/FLYBACK	76,436	(168,540)
SYSTEMS	8,494	(18,730)
MARGIN	15,025	(33,130)
DRY	216,712	(477,850)
PERSONNEL	--	(--)
PAYLOAD-ASCENT	--	(--)
RESIDUALS & RESERVES	14,812	(32,660)
INFLIGHT LOSSES	24,648	(54,350)
PROPELLANT-RCS	1,220	(2,690)
FUEL-FLYBACK	29,456	(64,950)
PROPELLANT-ASCENT	2,470,250	(5,446,900)
BLOW	2,757,098	(6,079,400)


Jack Olson

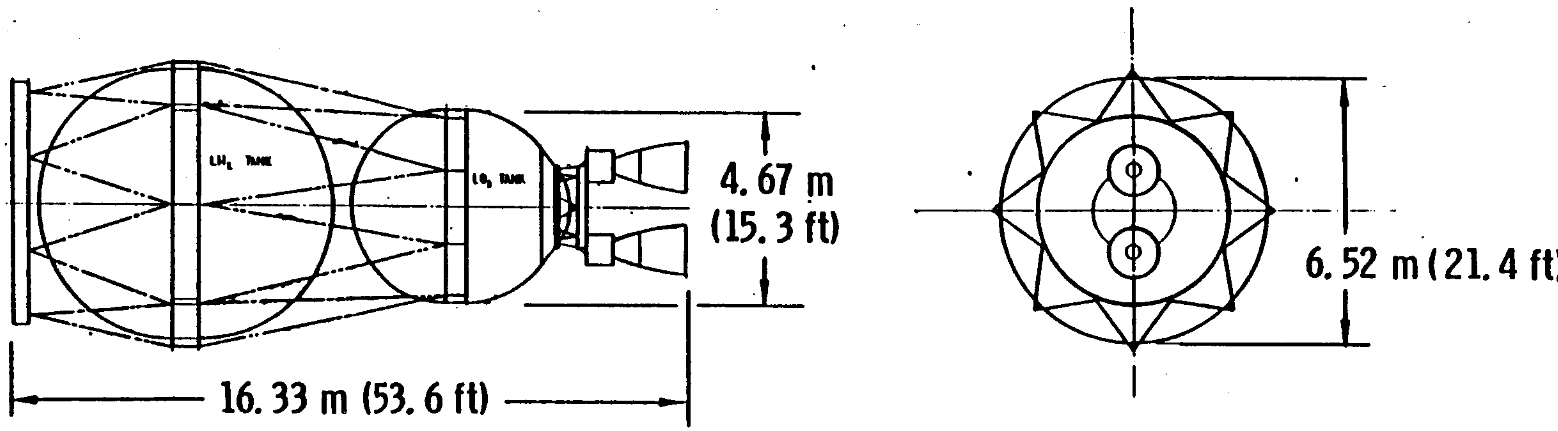
Accelerated Technology Impact on POTV



26,770 LBS ← DELIVERY PAYLOAD (WITH 75% RETURN) → 27,170 LBS

- INTEGRATED LOX/LH_2 SUBSYSTEMS ALLOW SINGLE POINT REFUELING
- THIS VEHICLE WELL PAST ANY PERFORMANCE THRESHOLDS!

POTV Configuration
Accelerated Technology

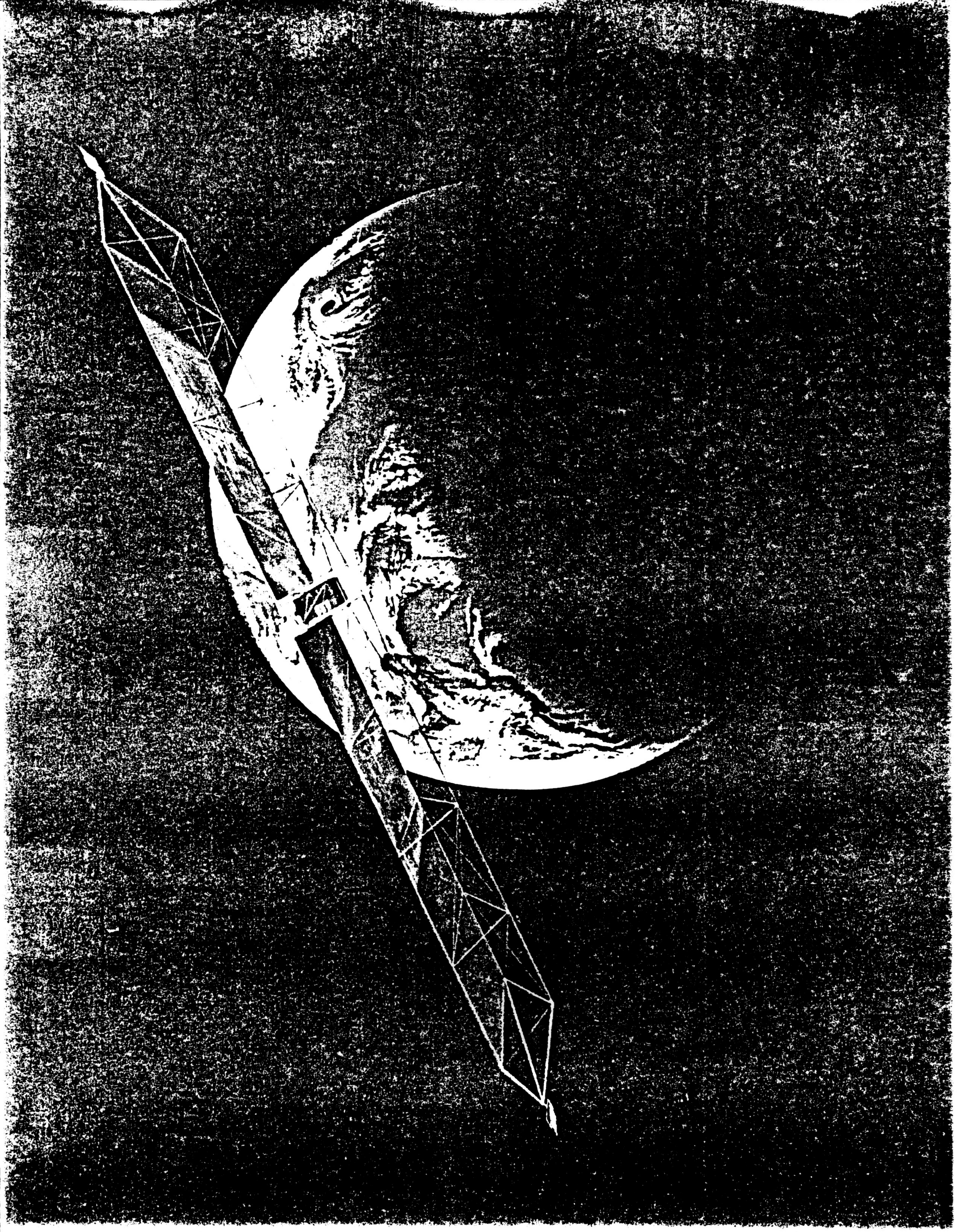


GROSS WEIGHT	96,579 KG	(212,957 LB)
P/L WEIGHT (75% RETURN)	12,322 KG	(27,170 LB)
RESERVES - MPS/APS/EPS	500 KG	(1,102 LB)
MAINSTAGE PROPELLANT - MPS	78,530 KG	(173,160 LB)
INERT WEIGHT	5,227 KG	(11,525 LB)

T/W @ STARTBURN = 0.188

POTV Weights

WEIGHTS	NORMAL GROWTH KG	NORMAL GROWTH (LB)	ACCELERATED TECHNOLOGY KG	ACCELERATED TECHNOLOGY (LB)
STRUCTURES & MECHANISMS	1,307	(2,881)	1,315	(2,899)
THERMAL CONTROL	487	(1,075)	490	(1,080)
MAIN PROPULSION SYSTEM (MPS)	753	(1,660)	753	(1,660)
AUX. PROPULSION SYSTEM (APS)	429	(945)	389	(857)
ELECT. POWER SYSTEM (EPS)	79	(175)	60	(132)
AVIONICS	213	(470)	183	(403)
MARGIN	327	(721)	318	(703)
DRY	3,595	(7,927)	3,508	(7,734)
PAYLOAD (75% RETURN)	12,141	(26,770)	12,322	(27,170)
RESIDUAL FLUIDS & GASES	880	(1,941)	874	(1,928)
RESERVES - MPS/APS/EPS	561	(1,238)	500	(1,102)
INFLIGHT LOSSES	237	(522)	238	(524)
NOMINAL PROP. - EPS	20	(44)	20	(44)
NOMINAL PROP. - APS	587	(1,295)	587	(1,295)
MAINSTAGE PROP. - MPS	78,531	(173,160)	78,530	(173,160)
GROSS	96,552	(212,897)	96,579	(212,957)

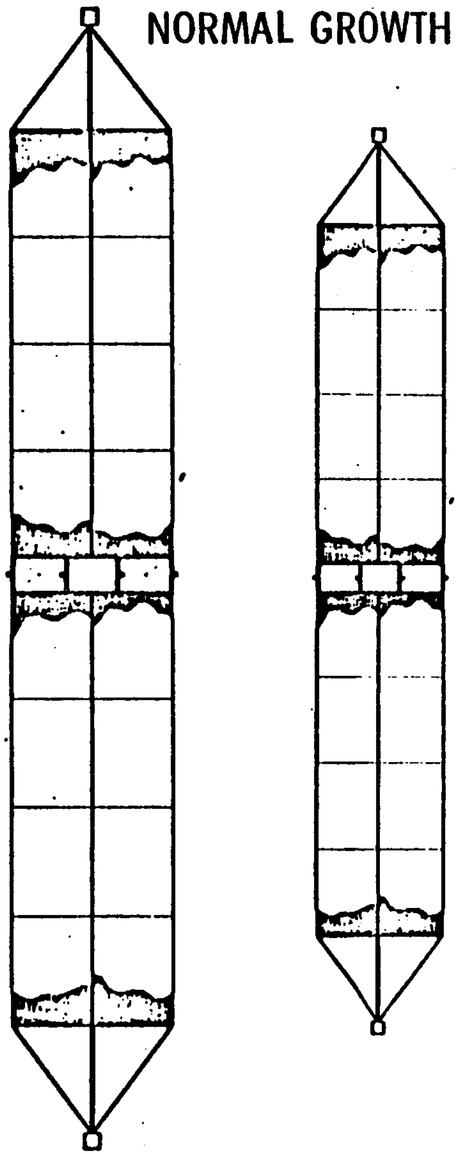


Accelerated Technology Impact On LCOTV

TR-104

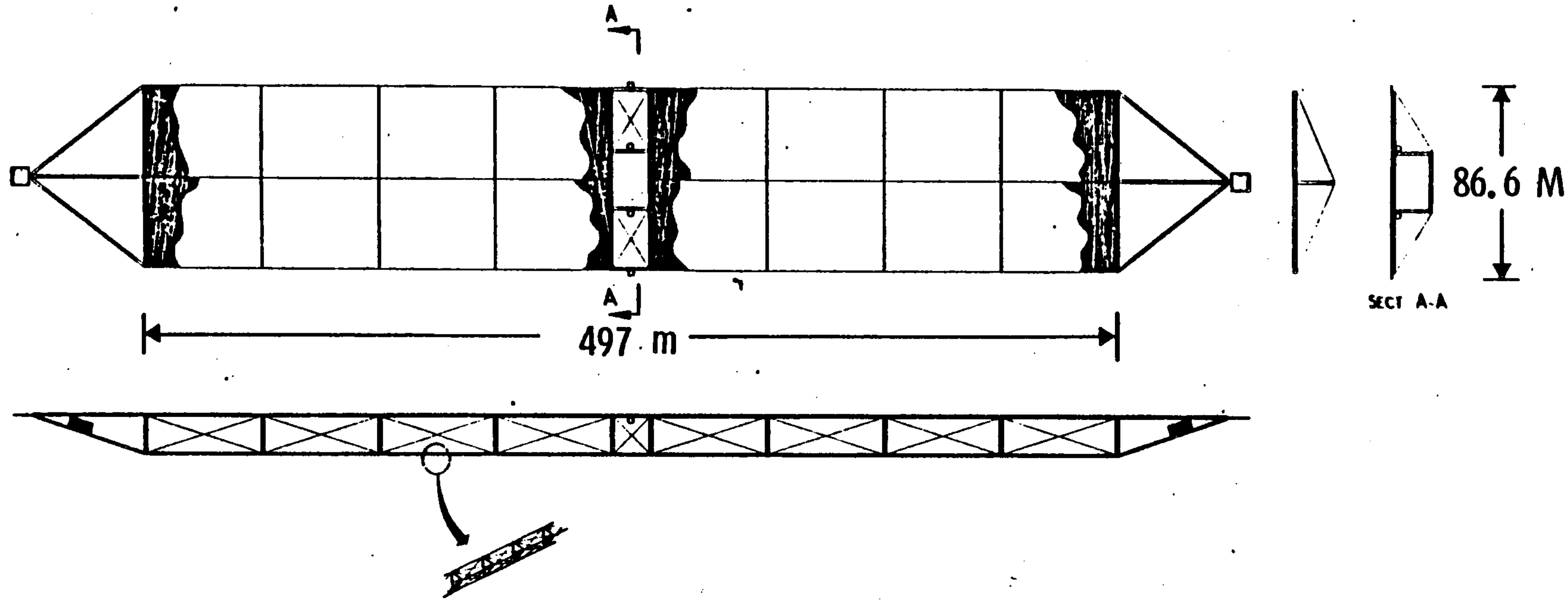
NORMAL GROWTH

ACCELERATED TECHNOLOGY



- Array Area Down By ~ 24%
- Dry Wgt. Down By ~ 7-1/2%
- Glow Delta ~ 7%
- Thrust Delta ~ 7%
- Vehicle "Problem" Basically Unchanged

LCOTV Configuration
Accelerated Technology



GROSS WEIGHT	=	289, 424 kg (638,180 lb)
P/L WEIGHT (0% RETURN)	=	226,757 kg (500,000 lb)
ARRAY AREA	=	41,495 m^2
NUMBER OF THRUSTERS	=	26
TOTAL THRUST	=	135 Newtons (30.4 lb)
T/W	=	4.76×10^{-5} g's

LCOTV
Characteristics and Weights

TR-99

WEIGHTS	NORMAL GROWTH KG	NORMAL GROWTH (LB)	ACCELERATED TECHNOLOGY KG	ACCELERATED TECHNOLOGY (LB)
STRUCTURE	4,057	(8,946)	2,880	(6,350)
POWER GEN.	26,831	(59,162)	22,212	(48,977)
PROPULSION	11,671	(25,735)	1,979	(4,364)
PROPELLANT SYSTEM	2,217	(4,888)	2,005	(4,421)
THERMAL CONTROL	377	(831)	68	(150)
AVIONICS	520	(1,147)	520	(1,147)
GROWTH*	9,339	(20,593)	5,075	(11,190)
DRY	55,012	(121,301)	34,739	(76,600)
PROPELLANT	29,744	(65,586)	26,901	(59,317)
RESERVES	892	(1,967)	784	(1,729)
PAYLOAD	227,000	(500,535)	227,000	(500,535)
START BURN	312,648	(689,389)	289,424	(638,180)
ARRAY AREA	54,416 m^2		41,495 m^2	
NO. OF THRUSTERS	206		26	
Isp	8,000		8,000	
TOTAL THRUST	145 N		135 N	

*Minimum 10% - Maximum 25%

SSTO — Cost Summary

($ IN MILLIONS)

TR-93

	NORMAL TECH.	ADV. TECH.
TOTAL PROGRAM	17,912.90	12,650.65
DDT&E	2,714.47	2,980.77
PROGRAM MANAGEMENT	86.98	65.51
ENGINEERING	833.50	1,848.44
MANUFACTURING	1,373.58	757.16
TEST	420.41	309.66
PRODUCTION	4,245.06	2,229.73
PROGRAM MANAGEMENT	377.48	183.88
SUSTAINING ENGINEERING	87.27	51.01
MANUFACTURING	3,780.32	1,994.85
PROD. TOOLING & S.T.E.	1,382.87	593.53
FLT. HARDWARE & SPARES	2,397.45	1,401.32
OPERATIONS	10,953.37	7,440.15
OPERATIONS SUPPORT	6,700.19	3,860.45
PROGRAM SUPPORT	1,576.75	1,577.20
SPARES PROCUREMENT	5,123.44	2,283.25
LAUNCH SUPPORT	4,253.18	3,579.70
OPERATIONS	3,177.18	2,998.87
PROPELLANT	1,076.00	580.83

• COST/FLT	$3.79M	$2.58M
• COST/LB	$126.21	$85.84
• ADVANCED TECHNOLOGY SAVINGS:	$5,262.25M	

HLLV — Cost Summary

($ IN MILLIONS)

	NORMAL TECH.	ADV. TECH.
TOTAL PROGRAM	13,346.41	10,992.75
DDT&E	6,243.87	4,618.50
PROGRAM MANAGEMENT	172.63	154.19
ENGINEERING	2,411.08	1,308.47
MANUFACTURING	2,825.81	2,412.35
TEST	834.35	743.49
PRODUCTION	2,252.21	1,937.59
PROGRAM MANAGEMENT	183.17	161.45
SUSTAINING ENGINEERING	51.92	44.49
MANUFACTURING	2,017.13	1,731.64
PROD. TOOLING & S.T.E.	590.84	509.35
FLT. HARDWARE & SPARES	1,426.28	1,222.29
OPERATIONS	4,850.33	4,436.66
OPERATIONS SUPPORT	2,968.43	2,705.12
PROGRAM SUPPORT	442.30	447.63
SPARES PROCUREMENT	2,526.13	2,257.49
LAUNCH SUPPORT	1,881.90	1,731.54
OPERATIONS	1,378.78	1,281.03
PROPELLANT	503.11	450.51
• COST/FLT =	$7.96 M	$7.18 M
• COST/LB =	$15.93	$14.59

• ADVANCED TECHNOLOGY SAVINGS: $2,353.66 M

POTV – Cost Summary
($ IN MILLIONS)

	NORMAL TECH.	ADV. TECH.
TOTAL PROGRAM	7,101.37	6,447.79
DDT&E	437.26	443.11
PROGRAM MANAGEMENT	5.67	6.44
ENGINEERING	313.52	322.17
MANUFACTURING	61.71	55.30
TEST	56.36	59.21
PRODUCTION	114.66	104.58
PROGRAM MANAGEMENT	15.58	14.59
SUSTAINING ENGINEERING	2.34	2.10
MANUFACTURING	96.74	87.89
PROD. TOOLING & S.T.E.	32.57	30.17
FLT. HARDWARE & SPARES	64.17	57.73
OPERATIONS	6,549.45	5,900.10
OPERATIONS SUPPORT	288.16	271.96
PROGRAM SUPPORT	44.40	41.59
SPARES PROCUREMENT	243.76	230.37
LAUNCH SUPPORT	6,261.29	5,628.14
OPERATIONS	213.75	213.75
PROPELLANT	6,047.54	5,414.39

- COST/FLT = $4.97M $4.29M
- COST/LB (LEO TO GEO) = $62.36 $53.56
- ADVANCED TECHNOLOGY SAVINGS: $653.58 M

LCOTV – Cost Summary

($ IN MILLIONS)

TR-91

	NORMAL TECH.	ADV. TECH.
TOTAL PROGRAM	3,276.06	3,236.08
DDT&E	387.93	596.42
PROGRAM MANAGEMENT	12.54	23.59
ENGINEERING	150.86	292.07
MANUFACTURING	128.18	130.38
TEST	96.35	150.38
PRODUCTION	1,930.12	1,911.38
PROGRAM MANAGEMENT	70.74	84.48
SUSTAINING ENGINEERING	51.81	61.50
MANUFACTURING	1,807.57	1,765.35
PROD. TOOLING & S.T.E.	194.51	164.20
FLT. HARDWARE & SPARES	1,613.06	1,601.15
OPERATIONS	958.01	728.33
OPERATIONS SUPPORT	574.78	355.53
PROGRAM SUPPORT	122.20	90.11
SPARES PROCUREMENT	452.58	265.42
LAUNCH SUPPORT	383.23	372.80
OPERATIONS	285.00	285.00
PROPELLANT	98.23	87.80

	NORMAL TECH.	ADV. TECH.
• COST/FLT	$17.11 M	$13.01 M
• COST/LB (LEO TO GEO)	$34.21	$26.01 M

• ADVANCED TECHNOLOGY SAVES - $39.98 M

Total System
Cost Summary

($ IN MILLIONS)

	NORMAL TECH.	ADV. TECH.
TOTAL PROGRAM	41,636.73	33,327.27
DDT&E	9,783.53	8,638.80
PROGRAM MANAGEMENT	277.82	249.73
ENGINEERING	3,708.97	3,771.14
MANUFACTURING	4,385.84	3,355.19
TEST	1,407.47	1,262.74
PRODUCTION	8,542.05	6,183.23
PROGRAM MANAGEMENT	696.69	444.40
SUSTAINING ENGINEERING	193.35	159.10
MANUFACTURING	7,701.72	5,579.73
PRDD. TOOLING & S.T.E.	2,200.79	1,297.24
FLT. HARDWARE & SPARES	5,500.93	4,282.49
OPERATIONS	23,311.15	18,505.24
OPERATIONS SUPPORT	10,531.56	7,193.06
PROGRAM SUPPORT	2,185.65	2,156.53
SPARES PROCUREMENT	8,345.91	5,036.53
LAUNCH SUPPORT	12,779.59	11,312.18
OPERATIONS	5,054.71	4,778.65
PROPELLANT	7,724.88	6,533.53

- ADVANCED TECHNOLOGY SAVINGS: $8,309.64 M

Findings

- ACCELERATED TECHNOLOGY PAYS OFF — 20% OF SYSTEM LCC
  ESPECIALLY FOR LAUNCH VEHICLES — <u>SSTO!</u>
- SO DOES NORMAL GROWTH!
  COMPOSITES - ENGINES - AVIONICS - CRITICAL COMPONENTS
- COMPOSITE STRUCTURES MOST IMPORTANT TECHNOLOGY
- DUAL EXPANDER-DUAL FUEL ENGINE CRITICAL FOR SSTO
- CCV - NO VERTICAL TAIL HAS EXCELLENT POTENTIAL
- EXTENDED LIFE ENGINES HAVE GREAT VALUE
- ACCELERATED TECHNOLOGY PUTS SSTO IN ATTRACTIVE CATEGORY
- TECHNOLOGY PAY OFF HIGHEST ON SSTO AND SINCE SSTO $$
  WERE LARGE PERCENT OF TOTAL SOME BIAS EXISTS
- HLLV IMPACT LESS DRAMATIC THAN SSTO BUT STILL SUBSTANTIAL
  - 18% REDUCTION IN LCC; 10% IN COST/FLT
- IMPACT ON OTV'S WAS NOT AS SIGNIFICANT

Findings

- TECHNOLOGY ANSWER SENSITIVE TO VEHICLE CONCEPT/CONFIGURATION
  - HORIZONTAL T.O. SSTO – TPS/STRUCTURES
  - LESS THAN TWO-STAGE HLLV
  - REDUCED SIZE HLLV – INCREASED SENSITIVITY TO TECHNOLOGY
  - BALLISTIC HLLV – TPS/STRUCTURES
  - SHUTTLE TENDED-SPACE BASED OTV – THERMAL CONTROL/ MAINTENANCE FREE DESIGN
  - AERO-ASSISTED OTV – TPS/GUIDANCE
  - GROUND BASED OTV – STRUCTURES/THERMAL CONTROL
  - "LOW G" CHEMICAL LCOTV – PROPULSION